REGION 5 RAC2

REMEDIAL ACTION CONTRACT FOR

Remedial, Enforcement Oversight, and
Non-Time Critical Removal Activities at Sites of Release
or Threatened Release of Hazardous Substances in Region 5

SUPPLEMENTAL FEASIBILITY STUDY REPORT

Remedial Investigation/Feasibility Study
OMC Plant 2 Site
Waukegan, Illinois
WA No. 018-RICO-0528/Contract No. EP-S5-06-01

July 2008

PREPARED FOR

U.S. Environmental Protection Agency

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Executive Summary

This supplemental feasibility study report re-examines the remedial action objectives (RAOs), technology screening, and alternative development and evaluation conducted for groundwater and dense non-aqueous phase liquids (DNAPLs) at the Outboard Marine Corporation, Inc. (OMC) Plant 2 site. The objective of the report is to incorporate the findings of the bench-scale and pilot-test activities into the alternatives developed that will remediate or control contaminated groundwater and DNAPL and provide adequate protection of human health and the environment.

RAOs for the groundwater were developed to protect human health and the environment based on the nature and extent of the contamination, resources that are currently and potentially threatened, and potential for human and environmental exposure as determined by the human health and ecological risk assessments. To meet the RAOs, preliminary remediation goals (PRGs) were developed to define the extent of contaminated media requiring remedial action at the OMC Plant 2 site (CH2M HILL, 2006).

Consistent with the RAOs and PRGs, remedial technologies and process options were identified and screened. Remedial technologies and process options that remained after screening were assembled into a range of alternatives. The potential alternatives encompass, as specified in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), a range of alternatives in which treatment is used to reduce the toxicity, mobility, or volume of wastes, but vary in the degree to which long-term management of residuals or untreated waste is required.

Based on the risks present at the site and the remaining remedial technologies and process options available after completion of the screening, the following alternatives were assembled and then evaluated against the seven criteria identified in the NCP. As required, a no further action alternative was also evaluated.

Groundwater	DNAPL
Institutional Controls and Monitored Natural Attenuation	Institutional Controls and Monitoring
In Situ Chemical Reduction	Extraction, Onsite Collection, and Offsite Destruction
Enhanced In Situ Bioremediation	In Situ Thermal Treatment
Groundwater Collection and Treatment with Monitored Natural Attenuation	In Situ Chemical Reduction Treatment
Groundwater Collection and Treatment to Maximum Contaminant Levels (MCLs)	
In Situ Thermal Treatment	
Permeable Reactive Barrier[1]	
Air Sparge Curtain[1]	

[1]Alternative only intended to be used in combination with other alternatives.

Contents

Executive Summary iii
Acronyms and Abbreviations ix
1. Introduction 1-1
1.1 Purpose 1-1
1.2 Organization 1-1
1.3 Site Description 1-2
1.3.1 Site Location 1-2
1.3.2 Background 1-2
1.3.3 Recent Actions at the Site 1-3
1.3.4 Summary of Pilot/Treatability Test Activities 1-5
1.4 Physical Site Setting 1-6
1.4.1 Local Demography and Land Use 1-6
1.4.2 Geologic Setting 1-7
1.4.3 Hydrogeologic Setting 1-7
1.4.4 Ecological Setting 1-8
1.5 Nature and Extent of Contamination 1-8
1.5.1 Nonaqueous Phase Liquids 1-8
1.5.2 Groundwater 1-10
1.5.3 Soil Gas and Indoor Air 1-11
1.6 Contaminant Fate and Transport 1-11
1.7 Human Health Risk Assessment 1-12
2. Development and Identification of ARARs, RAOs, and PRGs 2-1
2.1 Summary of Applicable or Relevant and Appropriate Requirements 2-1
2.1.1 Chemical-Specific ARARs 2-2
2.1.2 Action-Specific ARARs 2-2
2.1.3 Location-Specific ARARs 2-3
2.2 Remedial Action Objectives for Groundwater and DNAPL 2-4
2.3 Preliminary Remediation Goals for Groundwater 2-4
2.4 Extent of Groundwater Exceeding Preliminary Remediation Goals 2-6
3. Identification and Screening of Technologies 3-1
3.1 General Response Actions for Groundwater and DNAPL 3-1
3.1.1 No Further Action 3-1
3.1.2 Institutional controls 3-1
3.1.3 Containment 3-2
3.1.4 In Situ Treatment 3-2
3.1.5 Removal 3-2
3.1.6 Collection/Ex Situ Treatment/Discharge 3-2
3.2 Identification and Screening of Technology Types and Process Options 3-2
3.3 Technology and Process Option Screening for DNAPL 3-3
3.3.1 In Situ Treatment 3-4
3.3.2 DNAPL Collection 3-15
3.3.3 In Situ Soil Mixing 3-15

3.4 Technology and Process Option Screening for Groundwater 3-15
3.4.1 Containment 3-16
3.4.2 In Situ Treatment....3-16
3.4.3 Ex Situ Treatment....3-19
3.4.4 Discharge....3-19
4. Alternative Descriptions....4-1
4.1 Introduction 4-1
4.2 DNAPL Alternative Descriptions....4-1
4.2.1 DNAPL Alternative 1—No Further Action....4-1
4.2.2 DNAPL Alternative 2—Institutional Controls and Monitoring 4-1
4.2.3 DNAPL Alternative 3—Extraction, Onsite Collection, and Offsite Destruction....4-2
4.2.4 DNAPL Alternative 4—In Situ Thermal Treatment 4-2
4.2.5 DNAPL Alternative 5—In Situ Soil Mixing with In Situ Chemical Reduction....4-5
4.3 Groundwater Alternative Descriptions 4-7
4.3.1 Groundwater Alternative 1—No Further Action....4-7
4.3.2 Groundwater Alternative 2—Institutional Controls and Monitored Natural Attenuation....4-7
4.3.3 Groundwater Alternative G3—Source Zone In Situ Treatment....4-8
4.3.4 Groundwater Alternative G4—Groundwater Collection and Treatment 4-11
4.3.5 Groundwater Alternative G5—In Situ Thermal Treatment....4-13
4.3.6 Groundwater Alternative G6—Permeable Reactive Barrier....4-13
4.3.7 Groundwater Alternative G7—Air Sparge Curtain....4-14
5. Detailed Analysis of Alternatives....5-1
5.1 Introduction 5-1
5.2 Evaluation Criteria....5-1
5.2.1 Threshold Criteria 5-3
5.2.2 Balancing Criteria....5-3
5.3 Detailed Analysis of DNAPL Alternatives....5-5
5.3.1 Detailed Evaluation 5-5
5.3.2 Comparative Analysis 5-5
5.4 Detailed Analysis of Groundwater Alternatives 5-13
5.4.1 Detailed Evaluation 5-13
5.4.2 Comparative Analysis 5-14
6. References....6-1

Appendixes

A Detailed Cost Estimates for DNAPL Alternatives
B Detailed Cost Estimates for Groundwater Alternatives
C CSU Bench-Scale Evaluation Report and Addendum

Tables

1-1 Light Nonaqueous Phase Liquid Characterization 1-10
2-1 Groundwater Preliminary Remediation Goals 2-5
3-1 Remedial Technology Screening–Groundwater and DNAPL 3-5
4-1 Remedial Alternative Development 4-3
5-1 Detailed Evaluation of DNAPL Alternatives 5-7
5-2 Detailed Evaluation of Groundwater Alternatives 5-15

Figures

1-1 Site Location Map
1-2 Vicinity Features
1-3 Plans for Harborfront and North Harbor Area Development Districts

2-1 TCE DNAPL Area
2-2 Source Zone
2-3 Groundwater Total CVOC Concentrations

4-1 Alternatives G6 and G7 Installation Location

Acronyms and Abbreviations

°F	degrees Fahrenheit
µg/100 cm^2	micrograms per 100 square centimeters
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
ACM	asbestos-containing material
ARAR	applicable or relevant and appropriate requirement
AST	aboveground storage tank
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/sec	centimeters per second
COC	contaminant of concern
CPAH	carcinogenic polynuclear aromatic hydrocarbons
CSU	Colorado State University
CVOC	chlorinated volatile organic compound
DCE	dichloroethene
DESR	Data Evaluation Summary Report
DNAPL	dense nonaqueous phase liquid
DPE	dual phase extraction
DPT	Direct-push technology
DRE	destruction and removal efficiency
DUS	dynamic underground stripping
ECD	electron capture detector
EISB	enhanced in situ bioremediation
ELCR	excessive lifetime cancer risk
EO	Executive Order
EOS	edible oil substrate
EPRI	Electric Power Research Institute
ERA	ecological risk assessment
ERB	Emergency Response Branch
ERH	electrical resistance heating
ETI	Environmental Technologies Inc.
FR	*Federal Register*
FS	feasibility study
FSP	field sampling plan
Ft^2	square feet
ft/ft	foot per foot
ft/yr	feet per year
g/kg	grams per kilogram
GAC	granular activated carbon
Gpm	gallons per minute
HDD	horizontal directional drilled

HHRA	human health risk assessment
HI	hazard index
HPO	hydrous pyrolysis oxidation
IAC	Illinois Administrative Code
IC	institutional control
IEPA	Illinois Environmental Protection Agency
ISCO	in situ chemical oxidation
ISCR	in situ chemical reduction
ISTD	in situ thermal desorption
IWQS	Illinois Water Quality Standards
LDR	land disposal restriction
MCL	maximum contaminant limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MIP	membrane interface probe
MNA	monitored natural attenuation
NAPL	nonaqueous phase liquid
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NIOSH	National Institute of Safety and Health
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
NSSD	North Shore Sanitary District
O&M	operations and maintenance
OMC	Outboard Marine Corporation
OSHA	U.S. Occupational Safety and Health Administration
OU1	Operable Unit 1
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PID	photoionization detector
POTW	publicly owned treatment works
ppm	parts per million
PRB	permeable reactive barrier
PRG	preliminary remediation goal
PVC	polyvinyl chloride
RAO	remedial action objective
RATM	Remedial Alternatives Technical Memorandum
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
ROD	Record of Decision
SDWA	Safe Drinking Water Act
SFS	Supplemental Feasibility Study
SOW	statement of work
SPH	Six-Phase Heating™
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TACO	Tiered Approach to Cleanup Objectives
TBC	to be considered

TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TMV	toxicity, mobility, or volume
TSCA	Toxic Substance Control Act
USC	United States Code
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UTS	Universal Treatment Standard
UV	ultraviolet
VOC	volatile organic compound
WA	Work Assignment
WCP	Waukegan Coke Plant
Yd^3	cubic yards
ZVI	zero valent iron

SECTION 1

Introduction

1.1 Purpose

This supplemental feasibility study (SFS) report re-examines the remedial action objectives (RAOs), technology screening, and alternative development and evaluation conducted for the contaminated groundwater and the dense non-aqueous phase liquid (DNAPL) at the Outboard Marine Corporation, Inc. (OMC) Plant 2 site in Waukegan, Illinois. This document supplements the *Feasibility Study Report* (CH2M HILL, 2006) completed for the site in January 2007. The U.S. Environmental Protection Agency (USEPA), in consultation with the Illinois Environmental Protection Agency (IEPA), selected a remedy in September 2007 to address the contaminated soils, sediments, and building materials. In their Record of Decision (ROD), USEPA indicated that selection of the remedy to address the groundwater and DNAPL would be delayed until treatability/pilot tests were completed for these media (USEPA, 2007). This report incorporates the results of the test activities into the development and evaluation of alternatives.

The alternatives evaluated include those alternatives that will remediate or control the DNAPL and contaminated groundwater at the site to adequately protect human health and the environment. The potential alternatives encompass, as specified in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), a range of alternatives in which treatment is used to reduce the toxicity, mobility, or volume (TMV) of wastes, but vary in the degree to which long-term management of residuals or untreated waste is required. The assembled alternatives were then evaluated in accordance with the seven NCP evaluation criteria. Two additional criteria to be used in the evaluation of alternatives and the selection of the remedy—state/federal acceptance and community acceptance—will be addressed following public comment of the SFS.

1.2 Organization

This report consists of five sections. Section 1 provides an introduction and updates the site conceptual model based on the results of the treatability and pilot test activities.

The RAOs and preliminary remediation goals (PRGs) developed in the 2007 *FS Report* for the groundwater and DNAPL media are summarized in Section 2. A detailed review of applicable or relevant and appropriate requirements (ARARs) for this site is provided in Appendix A of the *FS Report* (CH2M HILL, 2006a).

Section 3 contains information about the general response actions that address the RAOs and introduces the identification and screening of the technology types and process options. Remedial technologies were screened to focus the detailed analysis on only those technologies most applicable to the DNAPL and groundwater.

In Section 4, the screened technologies were developed and assembled into remedial action alternatives that achieve some or all of the RAOs, provide a range of levels of remediation, and a corresponding range of costs.

The detailed analysis of the alternatives for the DNAPL and contaminated groundwater is presented in Section 5. The detailed analysis addresses the seven NCP evaluation criteria. The basis and detailed cost estimates for the alternatives are provided in Appendix A and B, for DNAPL and groundwater, respectively.

Reference documents used during the performance of the alternatives screening and preparation of this report are included in Section 6.

1.3 Site Description

The following sections briefly describe the physical location of the site; its operational history; the geologic, hydrogeologic, and ecological setting; the nature and extent of contamination; contaminant fate and transport; and summary of human health and ecological risks. A summary of results from previous investigations is presented in the *Field Sampling Plan* (FSP) (CH2M HILL, 2004), the *Remedial Investigation Report* (*RI Report)* CH2M HILL, 2006) and the *Data Evaluation Summary Report* (DESR) (CH2M HILL, 2008a).

1.3.1 Site Location

The OMC Plant 2 site is a 65-acre industrial property located at 100 East Seahorse Drive, on the lakefront in Waukegan, Illinois (Figure 1-1). The OMC Plant 2 building was a 1,036,000-square-foot (ft^2) former manufacturing plant. Approximately 400,000 ft^2 of the former manufacturing plant has since been demolished down to the building slab. The site also includes several parking lot areas to the north and south of the building and two polychlorinated biphenyl (PCB) containment cells in which PCB-contaminated sediment (dredged from Waukegan Harbor in the early 1990s) and PCB-impacted soil are managed. (Figure 1-2). These cells (the East Containment Cell and the West Containment Cell) are located north of the plant building.

The site is situated in an area of mixed industrial, recreational, and municipal land uses (Figure 1-2). The OMC facility is bordered to the north by the North Ditch and North Shore Sanitary District (NSSD) and to the east by the public beach and dunes along Lake Michigan. Sea Horse Drive forms the southern site boundary. Railroad tracks operated by the Elgin, Joliet, and Eastern Railway Company, and the A. L. Hanson Manufacturing Company (formerly OMC Plant 3) are located to the west of OMC Plant 2.

1.3.2 Background

OMC manufactured outboard motors from about 1948 until 2000 in the 1,036,000-ft^2 OMC Plant 2 facility. Plant 2 was a main manufacturing facility for OMC; the major production lines used PCB-containing hydraulic and lubricating/cutting oils, chlorinated solvent-containing degreasing equipment, and smaller amounts of hydrofluoric acid, mercury, chromic acid, and other similar chemical compounds.

OMC's manufacturing operations from 1969 to 1988 included vapor degreasing and solvent distillation with reported annual trichloroethylene (TCE) usage rates of up to 50,000 gallons per year in 17 degreaser units. In addition to the degreaser units, the facility utilized a distiller for the purpose of reclaiming solvents and a 5,500-gallon TCE tank housed in a semi-grade vault.

OMC filed for bankruptcy protection on December 22, 2000 and ceased manufacturing operations in August 2001. The OMC properties were abandoned and put up for sale by the Trustee during the bankruptcy proceedings. In November 2001, the bankruptcy trustee filed a motion to abandon OMC Plant 2. The bankruptcy trustee negotiated an emergency removal action scope of work with USEPA and IEPA that was approved by the court on July 17, 2002. The waste removal activities for the OMC Trust were completed in November 2002 and the Trust abandoned the OMC Plant 2 property on December 10, 2002.

USEPA assumed control of building security and utilities on December 10, 2002, and commenced a removal action to clean up more of OMC Plant 2 in spring 2003. The City of Waukegan took title to the OMC Plant 2 property in September 30, 2005 and is responsible for maintaining the building, property, and operation and maintenance (O&M) of the containment cells.

1.3.3 Recent Actions at the Site

Since the late 1970s, the OMC complex has been subject to investigation and remediation (primarily for PCBs). The information on the recent remedial activities conducted at the site is briefly summarized below.

Remedial Investigation

USEPA began a Remedial Investigation (RI) at the OMC Plant 2 site in 2004 to determine the nature and extent of contamination in sediment, soil, within the OMC Plant 2 building, and the groundwater. The *RI Report*, including the investigation results and human health and ecological risk assessments, was issued in April 2006. The RI identified the following potential environmental problems (CH2M HILL, 2006b):

- PCB-contaminated concrete floors, walls, and ceilings exist in the old die cast, parts storage, and metal working areas.
- Soil beneath the northern and southern parking lot areas and east of the plant contain PCBs and/or carcinogenic polynuclear aromatic hydrocarbons (CPAHs) at levels that exceed their respective preliminary cleanup goals.
- Chlorinated solvents in substantial quantities, including a TCE DNAPL pool, exist beneath the site.
- A chlorinated solvent groundwater plume potentially is migrating into Lake Michigan.

Feasibility Study and ROD

A Feasibility Study (FS) was initiated in 2005 to examine site cleanup alternatives designed to protect human health and the environment, and the *FS Report* was issued in December 2006 (CH2M HILL, 2006a). Based on the findings of the RI and FS, USEPA determined that PCBs and CPAHs in OMC Plant 2 site soil and sediment present unacceptable risks to current and future human and ecological receptors. In addition, PCB levels inside the OMC

Plant 2 building would also present unacceptable risks to future human receptors if left unaddressed.

The ROD issued for the site, selected a remedy for the soil and sediment and building media that consists of the following components (USEPA, 2007):

- The excavation of soil and sediment that contain concentrations exceeding 1 part per million (ppm) PCBs and/or 2 ppm CPAHs.
- The abatement of asbestos-containing material.
- The demolition and removal of OMC Plant 2 building materials, including removal of non-adhered lead-based paint and remaining universal waste.
- The decontamination and recycling of structural steel and other salvageable metal, if economically feasible.
- The offsite disposal of soil, sediment (as required), and building debris.

The ROD also noted the initiation of pilot-testing of potential clean-up methods for the groundwater and DNAPL.

Other Actions Conducted by USEPA or the City of Waukegan

High levels of PCB contamination were found in the dune area soils during the investigations conducted by the City of Waukegan and the USEPA. The highest PCB concentrations (730 milligrams per kilogram [mg/kg]) were detected in samples near the North Ditch and east of the East Containment Cell. In December 2005, USEPA's Emergency Response Branch (ERB) began a removal action in the dune area along the fence line near the East Containment Cell and an area in the South Ditch. The removal action included the excavation and offsite disposal of over 6,000 cubic yards (yd^3) of sandy soil containing 10 to 14,000 ppm Aroclor 1248 (Tetra Tech EM Inc., 2006).

USEPA's ERB also cleaned out several storm sewers leading from the OMC Plant 2 facility to prevent recontamination of the beachfront by residual PCBs discovered in the sewer lines.

Based on the results of the RI, the City of Waukegan hired a contractor to demolish the nearly 400,000 ft^2 of uncontaminated structures down to the concrete slabs beginning in August 2006. Nearly 600,000 ft^2 of contaminated structures remain standing at the site and will be demolished by the USEPA during the site cleanup.

The City of Waukegan and USEPA also removed the PCB-containing transformers except for one on the roof of the remaining building. The PCB-containing electrical transformers were disposed of offsite at a licensed facility in January 2007. In addition, an extensive amount of copper wire and electrical connectors from the plant were removed to reduce the incentive for scavengers to break into the facility and potentially be exposed to PCB contamination while scavenging for copper or other materials.

1.3.4 Summary of Pilot/Treatability Test Activities

The FS report identified two in situ treatment technologies (chemical reduction in the DNAPL source zones and enhanced in situ bioremediation [EISB] in the groundwater source zones) as viable response actions to address the source zones and the resulting groundwater plume of chlorinated volatile organic compounds (CVOCs). A pilot test was developed to determine whether the in situ technologies could be used as a major component of the groundwater remedy and how the selected in situ technology would be implemented full scale at the site.

Source Zones

The results of the RI indicate that the groundwater contamination is related to the use of chlorinated solvents, primarily TCE, in past manufacturing operations at OMC Plant 2. Data indicate that the chlorinated "parent compound" in groundwater (TCE) was released to the subsurface during manufacturing operations and created "source zones." Source zones are defined as portions of the aquifer that have particularly high dissolved phase TCE concentrations, and which may have residual DNAPL or high concentrations of adsorbed TCE that can continue to create and sustain dissolved phase plumes.

The overall objectives for the EISB pilot test of the source zones were as follows:

1) Evaluate the degree to which in situ treatment through substrate injection can reduce the concentrations of TCE and degradation products (cis-1,2-dichloroethene [cis-1,2-DCE] and vinyl chloride) in the target treatment source zones and downgradient monitoring locations.

2) Determine the overall effectiveness of in situ treatment for achieving complete reduction of TCE to nontoxic degradation products (such as ethene or ethane).

3) Monitor the duration that the injected substrates can maintain enhanced, relative to background, reducing conditions for in situ treatment.

4) Determine the radius of influence of the selected injection method.

An additional objective of the pilot test was to examine the effectiveness of two different amendments—a soluble substrate (such as sodium lactate) and an edible oil substrate (EOS™). Both amendments work to enhance the natural reductive dechlorination processes in the aquifer. The composition and historical performance for both amendments indicate that either could be effectively used in the EISB remedial alternative.

The EISB pilot test consisted of the following activities:

1. Injection well and monitoring well installation and groundwater sampling and analysis (including site-wide baseline and annual sampling events)

2. Injection of amendment

3. Post-injection performance monitoring

4. Follow-up injections, as needed

The description of the well installation and results of the site-wide groundwater sampling events are presented in the *DESR* (CH2M HILL, 2008a). The description and results of the amendment injections and the post-injection monitoring are presented in a separate *Enhanced In Situ Bioremediation Pilot Study Report* (CH2M HILL, 2008b).

DNAPL Area

While in situ biodegradation methods have been found to be effective for reducing dissolved phase contamination, they have not yet been shown to be highly effective for directly remediating nonaqueous phase liquid (NAPL). The presence of DNAPL outside the building in the eastern portion of Area 2 requires more active remedial alternatives than enhancing bioremediation. In situ soil mixing using a chemical reducing agent was selected to target the DNAPL area. The objective of pilot testing related to DNAPL was to evaluate the reduction of the mass of DNAPL and mass flux of dissolved phase contamination from remaining DNAPL achieved through shallow soil mixing of zero-valent iron (ZVI) and bentonite. Data collection activities included the following:

- Conducting a limited investigation to define the extent and thickness of the DNAPL area.
- Installing monitoring wells to establish existing groundwater conditions.
- Performing a bench-scale test to evaluate the optimum dosage and source for the ZVI, potential amendments to control hydrogen gas production, and enhance post-mixing soil strength. Colorado State University (CSU), the patent holder for this technology, performed the bench-scale testing

1.4 Physical Site Setting

1.4.1 Local Demography and Land Use

Current Conditions

The current land use in the vicinity of OMC Plant 2 is primarily marine-recreational and industrial, but also includes utilities and a public beach east of the site (Figure 1-2). Waukegan Harbor, south of the site, is an industrial and commercial harbor used by lake-going freighters and recreational boaters. The Larsen Marine Service, Inc. ("Larsen Marine") property lies between the OMC Plant 2 site and Waukegan Harbor. Larsen Marine uses Slip 4 for repair, supply, and as docking facilities for private boats.

The Lake County Board and the City of Waukegan classified land use areas in Lake County in 1987. Land surrounding the northern portion of Waukegan Harbor has been classified as urban, while the beach areas and water filtration plant properties are classified as open-space areas. The remaining land in the immediate harbor area is classified as special use (Lake County) or residential (City of Waukegan).

The site, surrounding properties, and the City of Waukegan obtain potable water from Lake Michigan. The city has no municipal potable wells. There are some private residential wells within the city limits at a distance from the site (URS, 2000).

Future Land Use

In December 2000, OMC declared Chapter 11 bankruptcy, and began liquidation in August 2001. Subsequently, the City of Waukegan purchased the Waukegan Coke Plant (WCP) site and also acquired the OMC Plant 2 property (Figure 1-2). The WCP and the OMC Plant 2 sites were rezoned to high-density residential, and the City and other entities are working to revitalize the Waukegan lakefront area.

In December 2003, the City of Waukegan amended its 1987 Comprehensive Plan to include the Waukegan Lakefront-Downtown and Lakefront Master Plan and supporting documents prepared by Skidmore, Owings & Merrill, LLP and its consulting team (City of Waukegan Ordinance No. 03-O-140). The master plan and documents provided by the City of Waukegan were reviewed with respect to the anticipated future land use of OMC Plant 2 and surrounding properties. The plan defines the northern portion of the OMC Plant 2 property as an "eco-park" development that transitions to mixed-use marina-related commercial and residential use on the southern portion of the property. Similar plans are anticipated for the WCP site. The City is in the early stages of its process of rezoning various lakefront parcels consistent with the master plan (Deigan, 2004). A concept of the City's vision for the harbor area is presented in Figure 1-3.

1.4.2 Geologic Setting

The subsurface materials encountered include near-surface fill materials above a naturally occurring sand unit that overlies clay till. The fill deposit extends from 2 to 12 feet below ground surface (bgs). Underlying the fill is a sand unit to a depth of about 25 to 30 feet. The sand is comprised of either poorly graded (SP) or silty sand (SM) with porosity values ranging from about 19 to 41 percent (average of 30 percent). Beneath the sand unit at a depth of about 30 feet is a dense, relatively impermeable (10^{-7} centimeters per second [cm/sec]), 70- to 80-foot-thick hard gray clay that forms the lower boundary of the unconfined aquifer. The surface of the till beneath the site is irregular, and generally dips gently to the east toward Lake Michigan, and is relatively flat from north to south. The unconsolidated materials overlie a sequence of dolomitic bedrock formations.

1.4.3 Hydrogeologic Setting

Groundwater is shallow and was encountered within the sand aquifer at depths ranging between 2 and 7 feet, depending on the ground surface elevation. The underlying till unit forms the lower boundary of this unconfined aquifer and likely acts as a barrier to the vertical contaminant migration.

In situ hydraulic conductivity testing indicates that the shallow portion is more permeable than the base of the sand aquifer. The average hydraulic conductivity for shallow and deep zones is 2.2×10^{-2} and 4.6×10^{-3} cm/sec, respectively. The geometric mean for the entire aquifer is 2.0×10^{-2} cm/sec.

The horizontal groundwater flow direction in the shallow portion of the aquifer is from west to east across the northern portion of the site (toward Lake Michigan) under an average horizontal groundwater gradient of 0.001 foot/foot (ft/ft). Shallow groundwater flow direction in the southern portion of the site is toward the south (Waukegan Harbor) with an average horizontal gradient of 0.002 ft/ft. Based on the average porosity of 30 percent and the average hydraulic conductivity value, the average linear groundwater velocity for the shallow zone is estimated to range from 70 to 150 feet per year.

The groundwater elevation map for the deeper portion of the aquifer indicates a flow direction pattern similar to the upper zone, with a portion in the middle of the site showing a very flat gradient (0.0004 ft/ft). Outside of this area, average horizontal gradients in the deeper portion of the aquifer range from 0.0008 to 0.002 ft/ft. The average linear groundwater flow velocities, using an average porosity of 30 percent, range from approximately 6 to 30 feet per year across the site in the deeper zone. Vertical gradients between the shallow and deep portions of the aquifer are almost non-existent.

1.4.4 Ecological Setting

The most significant ecological feature is the 13-acre dune area on the easternmost side of the OMC Plant 2 property, extending from the NSSD's southern property boundary including the North Ditch to the South Ditch (Figure 1-2). This portion of Waukegan Beach has never been developed with surface structures and is generally inaccessible. Wooded areas have been re-established east of the former seawall barrier and extend from the North Ditch to the South Ditch. Most of the remaining portions of the Waukegan Beach east of this tree line are rolling sand dunes with sporadic tree and natural grass land cover that lead eastward to a gently sloping beach.

Three wetland areas are represented by drainage ditches on the north and south edges of the area and by a small depression along the North Ditch near the lakeshore. A narrow terrace along the north side of the South Ditch contained significant amounts of conservative wetland species.

The Illinois Department of Natural Resources identified 13 plants species, 1 invertebrate species, and 5 bird species that are threatened or endangered (federal or state) and occur within 1 mile of OMC Plant 2 (Kieninger, 2005). The piping plover is the only threatened or endangered (federal or state) bird species known to have nested in the beach area east of the OMC Plant 2 site (IEPA, 1994). Four threatened or endangered plant species have been found at Waukegan Beach. The species are American sea rocket (*Cakile edentula,* state-threatened), seaside spurge (*Chamaesyce polygonifolia*, state-endangered), American beachgrass (*Ammophila breviligulata*, state-endangered), and Kalm's St. John's wort (*Hypericum kalmianum*, state-endangered).

1.5 Nature and Extent of Contamination

The findings of the recent field investigation relative to the nature and extent of contamination of the DNAPL and groundwater at the OMC Plant 2 site are described below.

1.5.1 Nonaqueous Phase Liquids

During the RI, DNAPL consisting of 1,600 grams per kilogram (g/kg) of TCE was encountered in the northern courtyard area east of the former metal working area. In addition, soil concentrations indicative of residual DNAPL were detected in a saturated soil sample collected from a boring in the area of the chip wringer. Based on these results, additional investigations were conducted in 2006 to define the lateral extent of the DNAPL.

The procedures and findings of the NAPL investigation are presented in the *DESR* (CH2M HILL, 2008a) and are summarized below.

TCE DNAPL

A limited subsurface investigation was conducted in November and December 2006 using direct-push technology (DPT) methods (i.e., Geoprobe®) to delineate the boundary of the DNAPL area in the courtyard north of the trim building and east of the metal working area. The focused investigation included advancing a total of 48 borings in the courtyard area and beneath the building to the base of the aquifer (Figure 2-1). Discrete groundwater samples were also collected from four boring locations to examine the occurrence of mobile and/or residual DNAPL. An amber-colored DNAPL with an oily appearance was observed at one location (SO-203). Based on the borings, the dimensions of the DNAPL source zone have been estimated as shown in Figure 2-1. Because the DNAPL area extends further beneath the building than anticipated, the southwestern extent could not be fully defined.

Polychlorinated Biphenyl Dense Nonaqueous Phase Liquid

During groundwater gauging activities, approximately 6 to 8 inches of DNAPL was encountered in a deep monitoring well (MW-517D) adjacent to the former hazardous waste storage building. The product was dark brown/black in color, highly viscous, and had minimal odor. DNAPL had not been observed at this location during the RI sampling in 2005. A sample of the DNAPL was collected with a bailer and sent to an offsite laboratory for characterization. Results indicated that the DNAPL contains 1,100 g/kg of Aroclor 1248. The 2005 groundwater data were reviewed and 61 micrograms per liter (μg/L) of Aroclor 1248 and 110 μg/L of Aroclor 1232 were detected in samples from the shallow (MW-517S) and deep (MW-517D) wells at this location, respectively.

In response to the presence of the PCB DNAPL, an additional well nest (MW-530S/D) was installed downgradient of the PCB-impacted well. In addition, a small-scale groundwater sampling event was conducted in March 2007 to delineate the extent of dissolved-phase PCBs in the area. The sampling included the shallow PCB-impacted well (MW-517S), upgradient monitoring wells (MW-510S and MW-510D), and downgradient wells (MW-513S, MW-513D, MW-530S, MW-530D, W-2, and W-3). PCBs were only detected in the groundwater sample from the shallow well above the DNAPL (MW-517S) at concentrations of 100 and 9.3 μg/L for Aroclors 1248 and 1260, respectively.

Light Nonaqueous Phase Liquid

The chip wringer is located on the north side of the building, in the western portion of the metal working area. In addition to the chip wringer, a 4,000-gallon TCE underground storage tank (UST) was reportedly located in this area of the plant. During the membrane interface probe (MIP) investigation conducted in 2005, elevated photoionization detector (PID) and electron capture detector (ECD) readings were recorded, indicating the presence of residual CVOC contamination. Soil and groundwater samples in the vicinity of MW-503S collected in 2005 did not contain compounds or concentrations indicative of LNAPL.

During the baseline groundwater sampling in February 2007, LNAPL was encountered in the shallow monitoring well (MW-503S) near the chip wringer. The product was approximately 2 to 3 inches thick, brown, viscous, and had an odor. A sample of the LNAPL was collected and sent to an offsite laboratory for characterization. The concentrations detected in the February sample were not as high as would be expected for an LNAPL. Therefore, an additional LNAPL sample was collected for re-characterization in September 2007. The LNAPL samples were of similar composition and magnitude and were comprised of the following:

TABLE 1-1
Light Nonaqueous Phase Liquid Characterization

Analyte	Concentration (mg/kg) 02/01/2007	Concentration (mg/kg) 09/01/2007
Aroclor-1248	810	580
Trichloroethene	4.4	6.6
trans-1,2-Dichloroethene	7.8	15
Chloroform	ND	14
m & p-Xylene	9.8	9
Tetrachloroethlyene	ND	8.2
o-Xylene	11	11
Ethylbenzene	12	14
1,1-Dichloroethene	14	19
Toluene	17	20
1,1-Dichloroethane	22	47
Methylene chloride	44	ND
Vinyl chloride	120	520
1,1,1-Trichloroethane	610	800
cis-1,2-Dichloroethene	830	1,600

ND = compound not detected

1.5.2 Groundwater

Site-wide groundwater samples were collected during the pilot test to establish the baseline water quality conditions prior to initiating the pilot test (February 2007) and to evaluate conditions during the test (September 2007). The procedures and findings of the site-wide groundwater sampling are presented in the DESR (CH2M HILL, 2008a).

The analytical results from the site-wide sampling were relatively consistent with the findings of the RI that the groundwater contamination is mainly related to the use of chlorinated solvents, primarily TCE, in manufacturing operations at OMC Plant 2. CVOCs were the most frequent volatile organic compound (VOC) found at concentrations exceeding groundwater standards. The distribution of the CVOCs appears limited in extent and appears as isolated areas rather than a single plume. The five dissolved-phase source areas identified in the RI were groundwater results. The CVOC plume extending south of the building does not appear to have migrated far offsite and does not extend to Waukegan

Harbor. The components of the CVOC concentrations include TCE, cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride. The presence of TCE degradation compounds and results of natural attenuation parameters collected during groundwater sampling indicate that the TCE area is being degraded by anaerobic reductive dechlorination.

1.5.3 Soil Gas and Indoor Air

Soil gas and indoor air sampling investigations were conducted during the RI to determine if volatilization from the groundwater plume may cause a potential inhalation risk to human health. Five soil gas samples were collected from the unsaturated zone at locations south of the OMC site in the vicinity of Larsen Marine. In addition to the soil gas samples, indoor air samples were collected from two of the Larsen Marine Service buildings.

In general, similar compounds were detected in the indoor air investigation as were found in the soil gas investigation results. The relative concentrations of OMC-related compounds (e.g., TCE and cis-1,2-DCE) and the predominance of compounds not detected in the groundwater samples indicate that volatilization from groundwater is probably not the major source of the VOCs detected in the soil gas samples or the indoor air samples from the Larsen Marine buildings.

1.6 Contaminant Fate and Transport

The primary contaminant release and transport mechanisms for the DNAPL and the contaminated groundwater occurring at the OMC Plant 2 site include the following:

- Volatilization of organic compounds from the groundwater, and migration offsite through the atmosphere. Volatilization of organic compounds from groundwater is not considered a major loss mechanism based on physical properties of the surface materials.
- Leaching of contaminants from source materials, including DNAPL, into groundwater and subsequent dissolved phase transport to groundwater discharge areas such as surface water bodies (Lake Michigan or Waukegan Harbor) is considered the most significant transport mechanism occurring at the site.
- The contaminants in the groundwater (CVOCs) have a higher mobility and are detected further away from the source areas. Based on the chemical properties of TCE, cis-1,2-DCE, and vinyl chloride and an average site-wide velocity, these CVOCs are estimated to travel at an average rate between about 40 and 60 feet/year, assuming no degradation of the CVOCs.

The groundwater data collected indicate that the chlorinated “parent compound” in groundwater (TCE) is being degraded by anaerobic dechlorination to transformation products (cis-1,2-DCE and vinyl chloride). Additionally, final and nontoxic degradation byproducts (ethane and ethene) were also detected at the site. Other natural attenuation data (geochemical and biochemical parameters) provide further evidence that the CVOCs are degrading in groundwater. Reductions in total CVOCs in groundwater, increases in daughter products, and trends in site conditions indicate that degradation is occurring. The natural attenuation screening of the September 2007 data and modeling indicate that monitored natural attenuation (MNA) is a potential remedial approach. The natural attenuation evaluation and the fate and transport modeling of CVOCs from source zones are presented in the DESR (CH2M HILL, 2008a)

1.7 Human Health Risk Assessment

A human health risk assessment (HHRA) was prepared as part of the *RI Report* using conservative assumptions and feasible exposure pathways that were based on current site conditions and both current and potential future site use. An exposure assessment and toxicity assessment were performed to evaluate potential exposure pathways and receptors and to develop cumulative risk estimates for comparison with USEPA target risk reduction goals. The results from this screening and the exposure and toxicity assessments indicate that, based on groundwater characterization results from the RI, the potential risks to human health were higher than USEPA target risk reduction objectives in different portions of the site. The estimated risks are based on the assumption that remedial actions are not conducted to address these concentrations. These estimated risks are also based on the assumption that the site is redeveloped for future residential and recreational uses. Chemicals in groundwater driving potential risks are CVOCs, including TCE and vinyl chloride. Under current conditions, there are no potentially complete exposure pathways (CH2M HILL, 2006b).

SECTION 2

Development and Identification of ARARs, RAOs, and PRGs

2.1 Summary of Applicable or Relevant and Appropriate Requirements

Remedial actions must be protective of public health and the environment. Section 121 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires that primary consideration be given to remedial alternatives that attain or exceed ARARs. The purpose of this requirement is to make CERCLA response actions consistent with other pertinent federal and state environmental requirements, as well as to adequately protect public health and the environment.

Definitions of the ARARs and the "to be considered" (TBC) criteria are given below:

- Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that directly and fully address a hazardous substance, pollutant, contaminant, environmental action, location, or other circumstance at a CERCLA site.
- Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law, which while not "applicable," address problems or situations sufficiently similar (relevant) to those encountered at a CERCLA site, that their use is well suited (appropriate) to the particular site.
- TBC criteria are non-promulgated, non-enforceable guidelines or criteria that may be useful for developing a remedial action, or are necessary for evaluating what is protective to human health and/or the environment. Examples of TBC criteria include IEPA Tiered Approach to Corrective Action Objectives (TACO) Tier 1 remediation objectives, USEPA drinking water health advisories, reference doses, and cancer slope factors.

Another factor in determining which requirements must be addressed is whether the requirement is substantive or administrative. "Onsite" CERCLA response actions must comply with the substantive requirements but not with the administrative requirements of environmental laws and regulations as specified in the NCP, 40 CFR 300.5, definitions of ARARs and as discussed in 55 Federal Register (FR) 8756. Substantive requirements are those pertaining directly to actions or conditions in the environment. Administrative requirements are mechanisms that facilitate the implementation of the substantive requirements of an environmental law or regulation. In general, administrative requirements prescribe methods and procedures (for example, fees, permitting, inspection, reporting requirements) by which substantive requirements are made effective for the purposes of a particular environmental or public health program.

ARARs are grouped into three types: chemical-specific, location-specific, and action-specific. The potential ARARs are listed in Appendix A of the *FS Report* (CH2M HILL, 2006a) along with an analysis of the ARAR status relative to remediation of the OMC Plant 2 site. The most important ARARs are discussed below.

2.1.1 Chemical-Specific ARARs

Chemical-specific ARARs include laws and requirements that establish health- or risk-based numerical values or methodologies for environmental contaminant concentrations or discharge. The chemical-specific ARARs for the OMC Plant 2 site can be classified into three categories: (1) residual concentrations of compounds that can remain at the site without presenting a threat to human health and the environment, (2) land disposal restriction (LDR) concentrations that must be achieved if the contaminated media that either is a characteristic hazardous waste or contains a listed hazardous waste is extracted and later land disposed, and (3) effluent concentrations that must be achieved in treatment of groundwater for discharge to surface water or discharge to a publicly owned treatment works (POTW).

Residual Concentrations

For groundwater, Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) and the Illinois Water Quality Standards (IWQS; Illinois Administrative Code [IAC] Part 620) are ARARs. Illinois TACO remediation objectives are not ARARs but are similar to the IWQS.

Land Disposal Restriction Concentrations

The Resource Conservation and Recovery Act (RCRA) LDRs would apply to remedial actions performed at the OMC Plant 2 site if waste generated by the remedial action (for example, contaminated soil or treatment residuals) contains a RCRA hazardous waste or is itself a characteristic hazardous waste. Listed hazardous wastes are not known to have been disposed of at the OMC Plant 2 site. As a result, excavated soils would not be required to be managed as listed hazardous wastes. If excavated and removed from the area of contamination (that is, where the soil is “generated”), the soil may be a characteristic hazardous waste, such as a D040 toxicity characteristic hazardous waste for TCE (toxicity characteristic leaching procedure [TCLP] greater than 0.5 milligrams per liter [mg/L]).

2.1.2 Action-Specific ARARs

Action-specific ARARs regulate the specific type of action or technology under consideration, or the management of regulated materials. The most important action-specific ARARs that may affect the RAOs and the development of remedial action alternatives are CERCLA, Toxic Substances Control Act (TSCA), and RCRA regulations.

Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA requires the selected remedy to meet the substantive requirements of all environmental rules and regulations that are ARARs unless a specific waiver of the requirement is granted. Waiver of ARARs may be requested (per NCP 300.430[f][1][ii][C]) based on any one of six circumstances. It is not anticipated that any ARAR waivers under CERCLA will be necessary.

Toxic Substances Control Act

TSCA regulates the remediation of soils contaminated with PCBs under 40 Code of Federal Regulations (CFR) 761.61. If excavated for disposal, it requires soil contaminated with PCBs at concentrations of 50 mg/kg or greater to be disposed of at either a hazardous waste landfill permitted under RCRA or at a chemical waste landfill permitted under TSCA. The self-implementing requirements for onsite cleanup of PCB remediation waste under 40 CFR 761.61 are not ARARs for CERCLA sites but are considered TBCs.

Resource Conservation and Recovery Act

RCRA regulations governing the identification, management, treatment, storage, and disposal of solid and hazardous waste would be ARARs for alternatives that generate waste that would be moved to a location outside the area of contamination. Such alternatives could include excavation of materials (for example, soils impacted with DNAPL). Requirements include waste accumulation, record keeping, container storage, disposal, manifesting, transportation, and disposal.

As discussed above, portions of the soil at the OMC Plant 2 site may be characteristic hazardous waste. If the soil is characteristic hazardous waste, RCRA LDRs would apply and treatment would be required in accordance with RCRA prior to disposal. This includes treatment of other underlying hazardous constituents as required by 40 CFR 268.9(a). The most likely LDR that would have to be met is the characteristic hazardous waste soil would have to be treated to 60 mg/kg TCE or 100 mg/kg PCB prior to disposal in a RCRA Subtitle C landfill. If the soil has no other underlying hazardous constituents, it could be treated to below the TCLP limit, rendering it nonhazardous and disposed of in a Subtitle D landfill. Nonhazardous waste soil would be disposed of in accordance with RCRA solid waste disposal requirements.

2.1.3 Location-Specific ARARs

Location-specific ARARs are requirements that relate to the geographical position of the site. State and federal laws and regulations that apply to the protection of wetlands, construction in floodplains, and protection of endangered species in streams or rivers are examples of location-specific ARARs. The most important location-specific ARARs for the OMC Plant 2 site are the following:

- Fish and Wildlife Coordination Act—Enacted to protect fish and wildlife when actions result in the control or structural modification of a natural stream or body of water. The statute requires that any action takes into consideration the effect that water-related projects would have on fish and wildlife, and then take action to prevent loss or damage to these resources.
- Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands), 50 CFR § 6 Appendix A—These are TBCs. They set forth USEPA policy for carrying out the provisions of Executive Orders (EOs) 11988 and 11990. EO 11988 requires that actions be taken to reduce the risk of flood loss; to minimize the impact of floods on human

safety, health, and welfare; and to restore and preserve the natural and beneficial values served by floodplains. EO 11990 requires that actions at the site be conducted in ways that minimize the destruction, loss, or degradation of wetlands. Small wetland areas are present along the North and South ditches between the OMC site and Lake Michigan.

2.2 Remedial Action Objectives for Groundwater and DNAPL

The USEPA Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites (USEPA, 1988a) and the NCP define RAOs as medium-specific or site-specific goals for protecting human health and the environment that are established on the basis of the nature and extent of the contamination, the resources that are currently and potentially threatened, and the potential for human and environmental exposure. PRGs are site-specific, quantitative goals that define the extent of cleanup required to achieve the RAOs. These PRGs for groundwater are developed and used in the FS, and they will be finalized in the ROD for the OMC Plant 2 site.

There is a potential for unacceptable risk from residential indoor inhalation of vapors from groundwater onsite. The risk assessment calculated an excess lifetime cancer risk (ELCR) of 6×10^{-4} for this exposure pathway. Also, there is a potential unacceptable risk from construction worker exposure to groundwater. The risk assessment estimated an ELCR of 6×10^{-4} and the hazard index (HI) of 7.

Although there are no current groundwater receptors at the OMC Plant 2 site, RAOs for groundwater were developed to minimize further migration of the contaminant plume and limit the time needed to remediate groundwater to below unacceptable risk levels. Groundwater within the DNAPL area onsite may not be able to be remediated to comply with ARARs within a reasonable time, so the RAO was modified for this area.

The RAOs for remediation of groundwater and DNAPL at the OMC Plant 2 site include the following:

- Prevention of residential indoor inhalation of VOCs that presents an HI greater than 1 or an ELCR greater than 1×10^{-4} to 1×10^{-6}.
- Prevention of construction worker exposure to groundwater, through contact, ingestion, or inhalation that presents an HI greater than 1 or an ELCR greater than 1×10^{-4} to 1×10^{-6}.
- Remediation of contamination in groundwater to concentrations below an HI greater than 1 or ELCR greater than 1×10^{-4} to 1×10^{-6}within a reasonable time frame.
- Remediation of DNAPL and groundwater within the DNAPL area to the extent practicable and minimize further migration of contaminants in groundwater.

2.3 Preliminary Remediation Goals for Groundwater

To meet the RAOs, PRGs were developed to define the extent of contaminated media requiring remedial action. This section summarizes the groundwater PRGs presented in the *FS Report* and uses the pilot test results to refine the volumes of affected groundwater exceeding the PRGs that will be addressed in the FS process. In general, PRGs establish media-specific concentrations of contaminants of concern (COCs) that will pose no unacceptable risk to human health and the environment. COCs are the list of chemicals that result in unacceptable risk based on the results of the risk assessment. The PRGs for groundwater were developed considering the following:

- Risk-based concentration levels corresponding to an ELCR between 1×10^{-4} and 1×10^{-6}, and/or a chronic health risk defined by an HI of 1.
- Chemical-specific ARARs/TBCs including federal MCLs for groundwater, IWQS for Class 1 groundwater, and IEPA TACO Tier 1 remedial objectives for soil and groundwater. The TACO Tier 1 remediation objectives are TBCs and are set at the HI equals 1 and ELCR values at 1×10^{-6}. The ELCR values could be modified upward to represent the values corresponding to a cumulative risk of 1×10^{-4}.
- Background concentrations of specific constituents.

PRGs were developed for groundwater based on the RAOs presented in the *FS Report* (CH2M HILL, 2006a). The SDWA federal MCLs, USEPA Region 9 PRGs, IWQS, and Illinois TACO Tier 1 values were compared to develop the groundwater PRGs. The federal MCLs and the Illinois values are the same for the three main COCs, TCE, cis-1,2-DCE, and vinyl chloride. The significantly lower USEPA Region 9 PRGs were used to ensure that the cumulative risk from ingestion of groundwater does not exceed the 1×10^{-4} ELCR value mandated by the NCP.

PRGs were also developed to address the RAO for volatilization of groundwater VOCs to indoor air. These values apply to TCE and vinyl chloride and are based on an ELCR of 1×10^{-6}. They were developed using the Johnson and Ettinger (1991) Model as described in the risk assessment (CH2M HILL, 2006b).

A summary of the PRGs for groundwater exposure pathways at the OMC Plant 2 site are included in Table 2-1.

TABLE 2-1
Groundwater Preliminary Remediation Goals
OMC Plant 2

Contaminant	Federal SDWA MCL (mg/L)	USEPA Region 9 Tap Water[a] (mg/L)	Illinois Water Quality Standard-Groundwater Class I (mg/L)	Illinois TACO Tier 1 Groundwater Criteria Class I (mg/L)	Groundwater Volatilization to Indoor Air (mg/L)
Volatile organic compounds (VOCs)					
Chloroform	0.0800	**0.0017**	NA	0.0002	NC
cis-1,2-Dichloroethylene	0.070	**0.61**	0.070	0.070	NC
trans-1,2-Dichloroethene	**0.100**	1.20	0.100	0.100	NC
Trichloroethylene	0.005	**0.00028**	0.005	0.005	0.0065
Vinyl chloride	0.002	**0.0002**	0.002	0.002	0.0003

TABLE 2-1
Groundwater Preliminary Remediation Goals
OMC Plant 2

Contaminant	Federal SDWA MCL (mg/L)	USEPA Region 9 Tap Water[a] (mg/L)	Illinois Water Quality Standard-Groundwater Class I (mg/L)	Illinois TACO Tier 1 Groundwater Criteria Class I (mg/L)	Groundwater Volatilization to Indoor Air (mg/L)
Pesticides/PCBs					
PCB-1016 (Arochlor 1016)	**0.0005**	0.0096	0.0005	0.0005	NA
PCB-1248 (Arochlor 1248)	0.0005	**0.00034**	0.0005	0.0005	NA
Metals					
Arsenic (Total)	0.010[b]	**0.00045**	0.050	0.050	NA
Manganese (Total)	NA	8.80	**0.150**	0.150	NA

Notes:
Selected PRG highlighted in bold with shaded background.
[a]USEPA Region 9 PRG presented represent values for an ECLR of 1×10^{-5}
[b]Arsenic MCL of 0.01 mg/L was promulgated in 2001 and went into effect on January 23, 2006.
NC – Not a contaminant of concern
NA – Not available or not applicable.
TACO – Tier 1 Groundwater Remediation Objectives for the Groundwater Component of the Groundwater Ingestion Route – 35 Illinois Administrative Code Part 742, Appendix B, Table E.

2.4 Extent of Groundwater Exceeding Preliminary Remediation Goals

The areas and depths of groundwater that exceed the PRGs were developed by comparing the most recent groundwater analytical results with the lowest applicable PRG. Based on the data collected during the MIP, soil, and groundwater investigations, five potential source areas were identified. These five areas shown on Figure 2-2 contain high dissolved-phase CVOC concentrations and may have residual DNAPL or high concentrations of adsorbed CVOCs which can continue to create and sustain dissolved-phase plumes.

The area exceeding the groundwater PRGs is defined by the area exceeding the PRGs for TCE and vinyl chloride of 0.028 and 0.2 µg/L, respectively (Figure 2-3). The areas exceeding the MCLs and the area exceeding 1 mg/L total CVOCs are also identified on Figure 2-3. These areas are included as potential target areas for active treatment. The area of groundwater exceeding the PRGs is estimated to be 53 acres. The areas exceeding MCLs and 1 mg/L total CVOCs are estimated to be 56 and 13 acres, respectively. The full saturated thickness of the sand aquifer is contaminated above PRGs in this area. The volume of groundwater exceeding PRGs is estimated at 155 million gallons, assuming an average saturated thickness of 30 feet and a porosity of 30 percent.

SECTION 3

Identification and Screening of Technologies

After the RAOs and PRGs were developed, general response actions consistent with these objectives were identified; general response actions are basic actions that might be undertaken to remediate a site (for example, no action, in situ treatment, or extraction and treatment). For each general response action, several possible remedial technologies may exist. They can be further broken down into a number of process options. These technologies and process options are then screened based on several criteria. Those technologies and process options remaining after screening are assembled into alternatives in Section 4.

The following sections present general response actions for the groundwater and DNAPL that may be applicable to OMC Plant 2. The technology screening for DNAPL was combined with groundwater because of the limited DNAPL extent and the similarities in technologies addressing high concentration source area groundwater and DNAPL. Technologies suited to only DNAPL are identified and discussed separately.

3.1 General Response Actions for Groundwater and DNAPL

The general response actions for groundwater at the OMC site include the following:

- No further action
- Institutional controls
- Containment
- In situ treatment
- Collection/treatment/discharge

For purposes of the general response actions, groundwater includes both the complete plume exceeding PRGs as well as several higher concentration source areas within the plume. DNAPL includes both the free-phase “pool” of TCE and PCB as measured as a separate phase during the RI and residual DNAPL, which is present in soils but by definition does not flow and is not extractable by pumping.

3.1.1 No Further Action

The no further action response includes no action for groundwater.

3.1.2 Institutional Controls

Institutional controls such as access restrictions or a restrictive covenant on the property deed of the OMC site limiting intrusive activities on the property may be necessary either as a standalone action or in concert with other actions. Groundwater and surface water monitoring may also be necessary to track the direction and rate of movement of the groundwater contaminant plume as well as to track changes in DNAPL thickness and whether the DNAPL is migrating.

3.1.3 Containment

Containment refers to minimizing the spread of groundwater contaminants through active or passive hydraulic gradient controls. Active gradient control can be accomplished with pumping wells, while passive gradient control can be achieved using a slurry or sheet-pile wall. Containment of groundwater can be effective in preventing the release of contaminants from the source areas and their subsequent migration.

Containment of DNAPL may be through active or passive hydraulic gradient controls. Active gradient control can be accomplished with injection wells or trenches, while passive gradient control can be achieved using a slurry or sheet pile wall.

3.1.4 In Situ Treatment

In situ treatment of groundwater entails treating the groundwater while it is in the aquifer, which can be achieved by applying physical/chemical, biological, or thermal techniques. Examples of possible approaches to in situ treatment of CVOCs in groundwater include chemical oxidation, MNA, chemical reduction, permeable treatment beds, resistive heating, thermal desorption, and/or biological treatment technologies. In situ treatment can be directed at the high concentration source areas or throughout the plume.

DNAPL would be treated in situ with surfactant or solvent washing/flushing, thermal treatment, soil mixing, in situ chemical oxidation, or in situ chemical reduction.

3.1.5 Removal

Residual DNAPL present in soils can be excavated and transported to an appropriate disposal facility. Some pretreatment of the contaminated DNAPL/soil will be required to comply with LDRs.

3.1.6 Collection/Ex Situ Treatment/Discharge

In this response action, groundwater would be extracted from the aquifer using pumping wells. The contaminants would then be removed from the water by physical, physical/chemical, chemical, or biological treatment. Disposal of groundwater can be accomplished by surface infiltration, subsurface injection, discharge to the POTW, or discharge to surface water.

DNAPL would be extracted from the subsurface using wells. Enhancements for DNAPL extraction such as use of surfactants or cosolvents are also possible. The collected DNAPL would then be disposed of offsite.

3.2 Identification and Screening of Technology Types and Process Options

In this section, the technology types and process options available for remediation of DNAPL and groundwater are presented and screened. An inventory of technology types and process options is presented based on professional experience, published sources, computer databases, and other available documentation for the general response actions identified in Sections 3.1, 3.2, and 3.3. Each technology type and process option is either a demonstrated, proven process, or a potential process that has undergone laboratory trials or bench-scale testing.

Each technology and process option is screened based on a qualitative comparison of effectiveness, implementability, and relative cost. This step may eliminate a general response action from the alternatives screening process if there are no feasible technologies identified. The objective, however, is to retain the best technologies and process options within each general response action for use in developing remedial alternatives. The evaluation and screening of technology types and process options are presented in Table 3-1. Those technologies and process options that are screened out based on effectiveness, implementability, and/or cost are highlighted in the tables.

As mentioned above, technology types and process options are screened in an evaluation process based on effectiveness, implementability, and relative cost. Effectiveness is considered the capability of the process option to perform as part of a comprehensive remedial plan to meet RAOs under the conditions and limitations present at the site. Additionally, the NCP defines effectiveness as the "degree to which an alternative reduces TMV through treatment, minimizes residual risk, affords long-term protection, complies with ARARs, minimizes short-term impacts, and how quickly it achieves protection." This is a relative measure for the comparison of process options that perform the same or similar functions. Implementability refers to the relative degree of difficulty anticipated in implementing a particular process option under regulatory, technical, and schedule constraints posed by the OMC site. At this point, the cost criterion is comparative only, and similar to the effectiveness criterion, it is used to preclude further evaluation of process options that are very costly if there are other choices that provide similar functions with similar effectiveness. The cost criterion includes costs of construction and any long-term costs to operate and maintain technologies that are part of an alternative.

The NCP preference is for solutions that utilize treatment technologies to permanently reduce the TMV of hazardous substances. Available treatment processes are typically divided into three technology types: physical/chemical, biological, and thermal, which are applied in one or more general response actions with varying results.

The technology types and process options remaining following screening and identified in the following sections are subject to refinement/revision based on further investigation findings, results of treatability studies, or recent technological developments.

3.3 Technology and Process Option Screening for DNAPL

Using the same methodology described in the preceding sections, Table 3-1 presents the screening of technology types and process options available for remediation of TCE DNAPL. Remedial technologies specific to the PCB DNAPL have not been developed as part of this FS. Generally, the response actions identified for TCE DNAPL are applicable to the PCB DNAPL. Bench scale testing is currently being planned for the PCB DNAPL to determine if treatment technologies specific to the PCB DNAPL can be identified. Potentially feasible technologies and process options for each general response action for remediation of TCE DNAPL include the following:

- No further action

- Institutional controls: deed restrictions, permits, and monitoring
- In situ treatment: chemical reduction, electrical resistance heating, and thermal desorption
- Collection: vertical wells, horizontal wells
- Excavation of DNAPL soils
- Offsite incineration of collected DNAPL and DNAPL soil

The rationale for selecting these process options is indicated in Table 3-1. The following sections highlight technologies where more detailed evaluation was necessary to distinguish between technologies or process options. These include the in situ treatment, DNAPL collection, and excavation, technology process options.

3.3.1 In Situ Treatment

Remedial technologies evaluated as part of the in situ response action for DNAPL at the OMC site are summarized below.

Chemical Reduction

Amendments such as emulsified ZVI or bentonite with ZVI are delivered into the DNAPL area using soil mixing methods. Soil mixing allows for treatment of the DNAPL in situ and/or stabilizes the DNAPL to limit the potential for future migration. The ZVI component will also treat the dissolved phase in the immediate area of the DNAPL to reduce the potential for a dissolved phase contaminant plume.

Soil mixing is also effective for residual DNAPL. Because residual DNAPL does not flow and cannot be removed by pumping, soil mixing effectively distributes the treatment amendments throughout the residual DNAPL zone. The cost of soil mixing is moderate due to the specialized equipment required to mix soil at a depth of 30 feet bgs and is primarily affected by the volume of the DNAPL area.

Thermal Treatment

In situ thermal treatment remedial technologies include two process options, electrical resistance heating (ERH) and in situ thermal desorption.

Electrical Resistance Heating Resistance heating generates physical conditions in the subsurface that enhance the release of contaminants from the subsurface. Heat is generated by installing electrodes into the subsurface and passing a current between the electrodes. The natural resistance of the soil results in subsurface heating. The heated contaminants are then collected near the ground surface as steam or extracted by pumping. The steam is condensed while VOCs remain primarily in the vapor phase and are treated and released. The cost of electrical resistance heating is moderate to high and is primarily affected by the volume of the area to be treated and the inflow of cold water from the aquifer extending the time to heat the treatment area to the target temperature.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
No Further Action						
None	None	No action.	None.	Implementable.	Zero.	Required for comparison.
Institutional Controls						
Access and Use Restrictions	Deed restrictions	Deed restrictions issued for property, source area, and/or downgradient groundwater exceeding the clean-up goals to restrict groundwater and land use.	Good.	Good.	Low.	Retained. Needed to ensure groundwater is not used until PRGs are attained.
	Permits	Regulations promulgated to require a permit for various activities (i.e., installation of wells, etc.).	Good.	Good.	Low.	Retained.
Alternative Water Supply		Variety of alternate water supply methods used to replace contaminated water supply. Not applicable to OMC site because there are currently no water wells that could be impacted by the site.	Good.	Good.	Moderate capital cost and high O&M	Not applicable. Potable water is already supplied by the city.
Monitoring		Short- and/or long-term routine monitoring is implemented to record site conditions, concentration levels, and natural attenuation parameters.				Critical to monitor effectiveness of any action.
Containment						
Vertical Barriers	Slurry walls	Trench around impacted area is excavated and filled with a slurry of low permeability material to provide a barrier.	Very effective for sites where containment of contaminant plumes threatening downgradient receptors is the primary remedial objective. At OMC, the primary objective is to return groundwater to meet the PRGs. Downgradient migration is very slow and the plume is not discharging to the harbor or lake. As a result, containment technologies for groundwater do not meet the remedial objectives.	Slurry walls are typically placed at depths up to 100 feet and are generally 2 to 4 feet in thickness. Installation depths over 100 feet are implementable using clam shell bucket excavation, but the cost per unit area of wall increases by about a factor of three. Slurry walls have been used for decades, so the equipment and methodology are readily available and well known; however, the process of designing the proper mix of wall materials to contain specific contaminants is less well developed.	Moderate – Costs escalate with depth. Costs likely to be incurred in the design and installation of a standard soil-bentonite wall in soft to medium soil range from \$6 to \$8 per square foot. These costs do not include variable costs required for chemical analyses, feasibility, or compatibility testing. Testing costs depend heavily on site-specific factors.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs. Slurry walls are not applicable to temporary containment needed for DNAPL excavation alternative.
	Vibrating beam	Vibratory force used to advance steel beam into the ground. A relatively thin wall of cement or bentonite is injected as the beam is withdrawn.	Continuity of wall is difficult to assess and leakage may occur.	Good, shallow depth to confining unit reduces potential for complications.	High. High capital costs for installation equipment.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	Grout curtains	Grout pressure injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Continuity of wall is difficult to assess and leakage may occur.	Good, shallow depth to confining unit reduces potential for complications.	Moderate.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Sheet piling	Interlocking steel piles are driven into subsurface along the boundaries of the impacted area. Sheet piling would be used as temporary shoring for DNAPL excavation.	Very effective for temporary shoring of soil during excavation.	Implementable to depths of about 30 feet needed at site.	Moderate.	Not retained for containment of groundwater. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs. Retained as a component of DNAPL excavation alternative to provide temporary shoring of excavation sidewalls for small areas.
	Permeability reduction agents	Cement grout or organic polymer injected into the soil matrix to reduce permeability.	Experimental process option.	Good in the shallow portion of the aquifer and moderate in the low portion of the aquifer where permeability is reduced.	Moderate.	Not retained for containment of groundwater. At OMC, containment technologies for groundwater do not meet the primary objective to return groundwater to meet PRGs. Retained as a component for DNAPL treatment.
	Ground freezing (cryocell process)	Ground freezing technology is used to form a flow-impervious, removable, and fully monitored ice barrier that circumscribes the contaminant source in situ.	Short-term effectiveness has been reported.	Requires piping installation, limited inflow of warm water, low groundwater velocity is best	High. High capital costs and high O&M costs.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
Horizontal Barriers	Block displacement	Controlled injection of slurry in notched injection holes produces a horizontal barrier beneath contamination.	Experimental process option.	Moderate.	High.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	Grout injection	Grout pressure injected at depth through closely spaced drilled holes.	Effective for small areas.	Good.	Moderate. Equipment intensive.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	Ground freezing	Similar to vertical barriers by ground freezing.	Experimental process option.	Moderate.	High.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	Liners	Liners placed to restrict vertical flow can be constructed of the same materials considered for cap construction.		Poor.	Moderate.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
Hydraulic	Vertical wells	Conventional groundwater extraction is pumping in vertical wells. Other extraction device include vacuum enhanced recovery, jet-pumping systems, etc.	Widely used and demonstrated effectiveness. Generally effective for hydraulic containment (i.e., horizontal migration) and ineffective for groundwater restoration.	Good. Common technology; often combined with other treatment technologies applied to the extracted groundwater in an integrated system.	Considered moderately cost-effective; good cost-effectiveness at lower permeability sites.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	Horizontal wells	Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.	Widely used and demonstrated effectiveness. Increasingly applied technology for increasing production rate from low permeability sites, or to access areas inaccessible with vertical well technology.	Requires sufficient area at one end of well for equipment and angled penetration. Often combined with other treatment technologies applied to the extracted groundwater in an integrated system	Significantly higher than vertical wells.	Not retained. At OMC, containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Drains	Underground gravel-filled trenches generally equipped with tile or perforated pipe are installed to collect groundwater.	Drains are not suited to high permeability formations where extraction wells are more effective.	Requires sufficient area and access. Often combined with other treatment technologies applied to the extracted groundwater in an integrated system	Low to Moderate depending on depth to groundwater. May require long piping runs to transfer collected groundwater to treatment system or discharge point.	Not retained. Containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
	One-pass trenching	Trenches backfilled with granular material provide preferred flow path for collection in pipe or sump. Groundwater collection technique to increase production rate from low permeability areas.	Widely used and demonstrated effectiveness. Effective for increasing groundwater production rate from low permeability areas. Used where aquifer is heterogeneous.	One-pass trenching limited to depths of 25 feet or less. Requires absence/removal of obstacles (e.g., utilities) along trench alignment.	Where implementable, less costly than traditional trenching methods (except small sites). Trenches are excessively costly in bedrock.	Not retained. Containment technologies for groundwater do not meet the primary remedial objective to return groundwater to meet PRGs.
In Situ Treatment						
Chemical	Chemical oxidation (ISCO)	Aqueous injection of oxidizing agents (peroxide/iron, permanganate, persulfate, or ozone) to promote abiotic in situ oxidation of chlorinated organic compounds.	Effective, requires good contact between target contaminant and reagent.	Commercially available. Moderate health and safety concerns depending on oxidant selected. High organic content in some groundwater samples would reduce efficiency.	Moderate to high. More costly than reductive processes because anaerobic groundwater would require much higher oxidant dosage to overcome the reducing environment. Oxidation is also not cost-effective for low-concentration dissolved VOC plumes.	Not retained. Anaerobic reductive dechlorination processes are more suitable to the present reducing environment in groundwater.
	Chemical reduction (ISCR)	Aqueous injection of reducing agents (zero valent iron, bioavailable carbon, hydrogen) to promote abiotic in situ reduction of chlorinated organic compounds.	Effective in treating site COCs. Most suitable as a source area treatment for high concentration groundwater.	Well developed technology with minimal equipment requirements.	Considered to have good potential for cost-effectiveness for source zones but is costly for low concentration plumes.	Retained for further evaluation in DNAPL and source areas.
	Permeable reactive barriers (passive treatment walls)	Permeable treatment units are installed across the flow path of impacted groundwater. As groundwater moves through the treatment wall, COCs are passively removed in the treatment zones by chemical and/or biological processes.	Very effective for sites where the primary remedial objective is containment of contaminant plumes threatening downgradient receptors. At OMC, the primary objective is to return groundwater to meet the PRGs. Downgradient migration is very slow and the plume is not discharging to the harbor or lake. As a result, containment technologies for groundwater do not meet the remedial objectives.	Easily implementable at depths of 30 feet or less.	Moderate to high. Where applicable, considered a cost-effective alternative to conventional remedial action technologies.	Retained for use in combination with other technologies. Technology alone does not meet the primary remedial objective to return groundwater to meet PRGs, but when used in combination can improve effectiveness of other technologies.
Physical	In-well air stripping (circulating Wells)	Groundwater is aerated and lifted within a well bore, re-infiltrates through a different strata of the formation, and creates groundwater circulation. Two systems would be needed because there is substantial difference between the shallow and deep aquifer permeability.	Effectiveness is affected by poor development of circulation zones due to heterogeneities in aquifer permeability. Typically, in-well air stripping systems are a cost-effective approach for remediating VOC-contaminated ground water at sites with deep water tables because the water does not need to be brought to the surface. Operate more efficiently with horizontal conductivities greater than 10^{-3} cm/sec and a ratio of horizontal to vertical conductivities between 3 and 10. A ratio of less than 3 indicates short circulation times and a small radius of influence. If the ratio is greater than 10, the circulation time may be unacceptably long.	Requires close well spacing, high iron concentrations may result in fouling.	Moderate to high. Extensive system capital investment required relative to alternatives.	Not retained due to the potential for well screen clogging, the shallow water table, and the need for separate shallow and deep systems as a result of the differing permeability.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Air sparging	Air is injected into saturated media to remove COCs through volatilization. May also be used at lower air flow rates to promote biodegradation of petroleum VOCs. Often coupled with soil vapor extraction (SVE) for collection/treatment of displaced VOCs.	Effective with tight well spacing (about 25 feet) in permeable, homogeneous media; significantly less effective in low permeability soils or stratified soils. Favors large saturated thickness and depth to groundwater (greater than 5 feet). Methane can be used as an amendment to the sparged air to enhance co-metabolism of chlorinated organics.	Requires close well spacing, high iron concentrations may result in fouling.	Low to moderate. Generally considered cost-effective where applicable.	Retained for use in combination with other technologies. Technology is effective for dissolved phase COCs at the site. Low flow rate application can improve effectiveness of other technologies.
	Dual phase extraction (DPE)	DPE is a technology that uses a high vacuum system to remove liquid (i.e., NAPL, contaminated groundwater) and soil vapor. The main purpose of the system is to lower the water table using high vacuum or groundwater pumping to expose the aquifer matrix to more rapid remediation via soil vapor extraction. Once above ground, the extracted vapors, liquid-phase organics, and/or groundwater are separated and treated.	Combination with complementary technologies (e.g., pump-and-treat) may be required to recover ground water from high-yielding aquifers. Use of DPE with these technologies can shorten the cleanup time at a site, as the capillary fringe is often the most contaminated area.	DPE is a full-scale technology and commercially available.	Moderate. Because of the number of variances involved, establishing general costs for dual phase extraction is difficult.	Not retained due to difficulty in dewatering the relatively permeable aquifer.
	Bioslurping	Bioslurping combines the two remedial approaches of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of hydrocarbon-contaminated soils. Vacuum-enhanced free-product recovery extracts LNAPLs from the capillary fringe and the water table.	Bioslurping is not applicable at sites such as OMC without LNAPL or aerobically biodegradable COCs.	Presence of subsurface piping may result in short-circuiting of system.	Low to moderate.	Not retained due to absence of LNAPL and presence of COCs that are not amenable to aerobic degradation.
	Pneumatic fracturing (PF)	High-pressure injection of air to create self-propped subsurface fracture patterns that minimize COC travel time via diffusion. Complements vapor and fluid extraction technologies. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	Effective in low permeability aquifers to increase permeability. Fracturing is an enhancement technology designed to increase the efficiency of other in situ technologies in difficult soil conditions. Tests results indicate that PF has increased the effective vacuum radius of influence nearly threefold and increased the rate of mass removal up to 25 times over the rates measured using conventional extraction technologies. In addition, numerous bench-scale and theoretical studies have been published.	Fracturing is widely used in the petroleum and water well construction industries and is commercially available for remediation activities.	Moderate. Equipment intensive.	Not retained because aquifer already has sufficient permeability.
	Hydraulic fracturing	High-pressure injection of fluids, followed by granular slurry, to create subsurface fracture patterns that minimize COC travel time via diffusion. Complements vapor or fluid extraction technologies.	Effective in low permeability aquifers to increase permeability. Fracturing is an enhancement technology designed to increase the efficiency of other in situ technologies in difficult soil conditions.	Fracturing is widely used in the petroleum and water well construction industries. It is commercially available for use in hazardous waste remediation.	Moderate. The cost per fracture is estimated to be $1,000 to $1,500, based on creating four to six fractures per day.	Not retained because aquifer already has sufficient permeability.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Hot water or steam flushing/stripping (i.e., hydrous pyrolysis/ oxidation [HPO])	Steam is forced into an aquifer through injection wells. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and treated.	Increases the rate of VOC removal. The process is applicable to shallow and deep contaminated areas and readily available mobile equipment can be used.	Implementable though vapor recovery may be difficult due to thin unsaturated zone and presence of piping network below building.	Very high due to heating equipment and power requirements.	Not retained due to extensive subsurface piping network beneath building.
	Electrical resistance heating (ERH)	ERH is an electrical resistance heating technology that delivers separate electric phases through electrodes placed in a circle around a soil vent, which promotes in situ generation of steam to vaporize target compounds. Vapors recovered in an SVE system and treated as needed to remove VOCs from air discharge.	Effective for treatment of VOCs in shallow soils.	Implementable. Requires that soils remain moist to ensure effective transfer of electricity and heat to aquifer.	High, power consumption costs vary.	Retained for further evaluation in DNAPL and source areas.
	In situ thermal desorption (ISTD)	The aquifer is heated in situ with heating elements. The heating results in vaporization of water and constituents for collection by a heated vapor extraction well.	Effective for treatment of VOCs and SVOCs in soils and groundwater with low gradients.	Implementable. Requires accurate conceptual model to ensure heating elements are installed below contamination, vapor migration outside of collection area is a concern, potential to mobilize DNAPL.	High capital and O&M costs for equipment and power. If NAPL is recovered, disposal and treatment costs increase.	Retained for further evaluation in DNAPL and source areas.
	Dynamic underground stripping (DUS)	A combination of in situ steam injection, electrical resistance heating and fluid extraction to enhance contaminant removal from the subsurface. Similar to enhanced soil vapor extraction, except that it also treats groundwater contamination.	DUS has been effectively used for high concentration source areas. High cost makes it unsuitable to low concentration dissolved phase contamination.	Implementable. Treated soils can remain at elevated temperatures for years after cleanup stimulating re-growth of biological community. Soil venting can accelerate the cooling process. DUS/HPO is being field tested at several sites. Additional data on long-term routine operating experience with DUS/HPO is needed to better plan future applications	Very high costs due to relatively extensive capital system requirements, but becomes more cost effective in larger applications.	Not retained due to more cost-effective options available for site contaminants.
Biological	Enhanced reductive dechlorination	Subsurface delivery of electron donors hydrogen, lactate, food-grade oils, corn syrup, etc. within the target zone to stimulate anaerobic biodegradation of chlorinated compounds by reductive dechlorination.	Very effective when used to enhance existing anaerobic conditions for remediation of CVOCs. Typically applied to high concentration source areas rather than low dissolved phase groundwater contamination.	Implementable. Site-specific bench and/or pilot-scale testing recommended, relies on advective transport of amendments.	Low to Moderate. Will in many cases be more cost-effective than aerobic process since maintenance of aerobic conditions is not required.	Retained for further evaluation for groundwater.
	Natural attenuation	Short- and/or long-term routine monitoring is implemented to record site conditions, concentration levels, and natural attenuation parameters. Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce concentrations to acceptable levels.	Good. Demonstrated to be occurring at the OMC site. Less generation or transfer of remediation wastes. Less intrusive as few surface structures are required. May be applied to all or part of a given site, depending on site conditions and cleanup objectives. Natural attenuation may be used in conjunction with, or as a follow-up to, other (active) remedial measures. Overall cost will likely be lower than active remediation. Longer time frames may be required to achieve remediation objectives, compared to active remediation.	Good regulatory agency acceptance.	Generally, the lowest cost alternative was applicable. The most significant costs associated with natural attenuation are most often due to monitoring requirements.	Retained for further evaluation for groundwater.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize, and destroy organic/inorganic contamination in ground water, surface water, and leachate. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phyto-degradation and phyto-volatilization.	Not effective for remediating groundwater to depths of 30 feet bgs as is needed at OMC.	Most applicable for control of shallow groundwater plumes. High concentrations of hazardous materials can be toxic to plants.	Low to moderate. Where applicable, considered one of the most cost-effective options available. Construction estimates for phytoremediation are $200K/acre and $20K/acre for operations and maintenance.	Not retained due to ineffectiveness in treating groundwater to depths of 30 feet as needed at OMC.
Removal						
Excavation	Excavation	Excavation of DNAPL-impacted soils can use ordinary construction equipment backhoes, bulldozers, and front-end loaders. Excavation of DNAPL soils at depths of 30 feet would require steel sheet piling for stabilizing the excavation walls.	Very effective because limits of contamination can be observed during excavation.	Excavation combined with offsite treatment and disposal of DNAPL soil is well proven and readily implementable technology.	High costs for deep excavation and required dewatering.	Not retained. Shoring required for excavation and dewatering would be cost prohibitive.
Collection						
Hydraulic	Vertical wells	Conventional groundwater extraction is pumping in vertical wells. Other extraction devices include vacuum enhanced recovery, jet-pumping systems, etc.	Widely used and demonstrated effectiveness.	Implementable.	Low. Least cost groundwater extraction tech technology.	Retained for further evaluation for DNAPL and groundwater.
	Horizontal wells	Drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling.	Widely used and demonstrated effectiveness. Increasingly applied technology for increasing production rate from low permeability sites, or to access areas inaccessible with vertical well technology.	Implementable.	Moderate. Significantly higher than vertical wells.	Retained for further evaluation as a component/enhancement of other alternatives for areas beneath the building or in DNAPL area.
	Drains	Underground gravel-filled trenches generally equipped with tile or perforated pipe are installed to collect groundwater.	Although they may be effective, drains are not suited to high permeability formations where extraction wells are more effective.	Implementable.	Moderate to high. May require long piping runs to transfer collected groundwater to treatment system or discharge point.	Not retained. Groundwater is more effectively removed from the high permeability aquifer materials using vertical wells.
Ex Situ Treatment						
Chemical	Chemical oxidation (e.g., ultraviolet [UV] oxidation)	Oxidizing agents are used to destroy organic contaminants in an ex situ reactor. Potential oxidizing agents are UV radiation, ozone, and/or hydrogen peroxide/ferrous iron, or permanganate.	Proven effectiveness for most CVOCs. Oxidant selection critical as not all oxidants are equally effective on all compounds.	Good. Treatability testing necessary. No residual to regenerate. No VOC air emissions.	High.	Retained for further evaluation for groundwater.
	Solar detoxification	Solar detoxification is a process that destroys contaminants by photochemical and thermal reactions using the UV energy in sunlight. Contaminants are mixed with a semiconductor catalyst such (e.g., titanium dioxide), and fed through a reactor which is illuminated by sunlight. Ultraviolet light activates the catalyst, which results in the formation of reactive chemicals known as “radicals.” These radicals are powerful oxidizers that break down the contaminants into non-toxic byproducts such as carbon dioxide and water.	Poor effectiveness for site COCs would require very large shallow ponds to allow photolysis but most losses would be via volatilization. Could not be operated during winter months.	The technology has been field tested; limited sunlight in this area of the country reduces practicality of this technology.	High.	Not retained due to poor effectiveness and operational constraints.

TABLE 3-1
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OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Chemical reduction	Reducing agents (zero valent iron) are used to destroy organic contaminants in an ex situ reactor. For example, CVOCs are reduced to carbon dioxide and water.	Effective for treating site COCs though a treatment bed would be very large and costly at the high anticipated flow rates extracted from the aquifer.	Long contact time between reducing agent and groundwater may be required.	Moderate, cost dependent on reducing agent selected and life of reducing agent.	Not retained because other more cost-effective technologies such as air stripping and UV/oxidation are available.
	Precipitation	This process transforms dissolved compounds into an insoluble solid, facilitating the compound's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation. It is used as a pretreatment process with other technologies (such as chemical oxidation or air stripping), where the presence of metals would interfere with treatment.	Effective in treating metals. Not applicable to site COCs.	Implementable. Commonly applied technology.	Moderate to high. The primary capital cost factor is design flow rate. Capital costs for 20-gpm and 65-gpm packaged metals precipitation systems are approximately $85,000 and $115,000, respectively. Operating costs (excluding sludge disposal) are typically in a range from $0.30 to $0.70 per 1,000 gallon of ground water containing up to 100 mg/L of metals.	Not retained because it is not applicable to site contaminants.
	Ion exchange	Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use.	Does not work well for mixed organic contaminants.	This technology has long been used in industry and is commercially available.	The cost for a typical ion exchange system ranges from $0.30 to $0.80 per 1,000 gallons treated. Key cost factors include pretreatment requirements, discharge requirements and resin utilization, and regenerant used and efficiency.	Not retained because it is not applicable to site contaminants.
	Hydrolysis	Destruction of contaminant through hydrolytic breakage of chemical bonds at elevated pH and high temperatures to aid in the breakage of chemical bonds	Requires excessively high temperatures to aid in the breakage of chemical bonds.	Moderate, treatment rates impact O&M requirements.	High, Requires high volumes of pH amendments or high energy inputs to raise temperatures.	Not retained due to limited effectiveness on CVOCs.
	Electrochemical reduction	Electrochemical treatment changes the oxidation state of ions in solution to a preferred and treatable state through the application of an electrolyte solution.	Effective for appropriate contaminants.	Moderate for low flow rates, high flow rates may require additional or larger electrodes.	High	Not retained because it is not applicable to site contaminants.
Physical Treatment	Separation	Separation processes seek to detach contaminants from their medium (i.e., ground water and/or binding material that contain them). Ex situ separation of waste stream can be performed by many processes: (1) distillation, (2) filtration/ ultrafiltration/ microfiltration, (3) freeze crystallization, (4) membrane evaporation, and (5) reverse osmosis.	Moderate.	Moderate.	High. High capital costs and O&M requirements.	Not retained because more cost effective options are available.

TABLE 3-1
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OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Liquid-phase carbon adsorption	Liquid phase carbon adsorption is a full-scale technology in which ground water is pumped through one or more vessels containing activated carbon to which dissolved organic contaminants adsorb. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place, removed and regenerated at an off-site facility, or removed and disposed. The two most common reactor configurations for carbon adsorption systems are the fixed bed and the pulsed or moving bed.	Effective for removal of TCE and cis-1,2-DCE. Less effective for VC removal. The technology is well proven, and is frequently part of remedial designs. The bed-life of GAC is usually short-term; however, if concentrations are low enough, the duration may be long-term.	Proven technology. O&M costs may be high depending on system loading and resulting rate of carbon use.	Moderate to high. There are costs to regenerate and replace GAC. Costs are also lower at higher flow rates.	Retained for further evaluation for groundwater.
	Air stripping	Air stripping is a full-scale technology in which volatile organics are partitioned from ground water by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. Treatment of air emissions may be necessary.	Removal efficiencies around 99 percent are typical for towers that have 4.6 to 6 meters (15 to 20 feet) of conventional packing and are removing compounds amenable to stripping. Removal efficiencies can be improved by adding a second air stripper in series with the first, heating the contaminated water, or changing the configuration of packing material. Thermal units for treating air stripper emissions can be used as a source of heat.	Implementable. O&M on the unit due to precipitation on the components. Air strippers are commercially available and widely used.	Moderate to high. Costs increase significantly if air emissions require treatment. At OMC, this may be significant because vinyl chloride is not easily removed from air with low cost GAC. A major operating cost of air strippers is the electricity required for the ground water pump, the sump discharge pump, and the air blower. As a general rule, pumps in the 1 to 20-gpm range require from 0.33 to 2 horsepower (HP); from 20 to 75 gpm power ratings are 1 to 5 HP; and from 100 to 600 gpm, power ratings range from 5 to 30 HP.	Retained for further evaluation for groundwater.
Biological Treatment	Aerobic cometabolic bioremediation	Organics in wastewater oxidized through the use of a mixed culture of organisms in aerobic conditions. Bioreactor combines contaminants, inducers and electron acceptor (oxygen) to enhance aerobic biodegradation. Inducers serve as carbon sources that activate aerobic enzyme systems known to degrade chlorinated VOCs.	Need sufficient organic substrate to sustain organisms.	This is a well developed technology that has been used for many decades in the treatment of municipal and industrial wastewater. However, only in the past decade, studies have been performed to evaluate the effectiveness of bioreactors in treating ground water and leachate from hazardous waste sites. Bioreactor equipment and materials are readily available.	High, requires time to establish biological community, may require addition of substrate if contaminant loading is not sufficient.	Not retained due to more cost-effective options available for site contaminants.
	Anaerobic bioremediation	Organics in wastewater oxidized through the use of a mixed culture of organisms in anaerobic conditions. Bioreactor containing contaminants and electron donors to stimulate anaerobic biodegradation of chlorinated compounds by reductive dechlorination.	Need sufficient organic substrate to sustain organisms. May be effective for CVOCs.	Well-developed technology. Requires sufficient space for large system depending on pumping rate. O&M intensive.	Not cost-competitive with air stripping for the relatively low organic strength water.	Not retained due to more cost-effective options available for site contaminants.

TABLE 3-1
Remedial Technology Screening–Groundwater and DNAPL
OMC Plant 2

Remedial Technology	Process Options	Descriptions	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Offsite incineration	High temperatures, 870 to 1,200°C (1,400 to 2,200°F), are used to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Incinerator designs are geared towards different waste streams and different end products, and operating temperatures vary with the different designs. Incineration is different from other thermal technologies in that it oxidizes bulk quantities of waste that may be in liquid and solid phase.	The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99 percent requirement for hazardous waste and can be operated to meet the 99.9999 percent requirement for PCBs and dioxins.	Implementable.	Very high.	Retained for further evaluation for disposal of collected DNAPL and DNAPL contaminated soil.
Discharge						
Wastewater discharge	Land application	Liquid wastes that are primarily organic are incorporated into the upper soil horizon so they can be degraded, transformed, or immobilized.	Poor effectiveness for CVOCs because they are not readily degradable aerobically.	Sufficient space onsite not available and would conflict with future residential land use onsite.	Low to moderate.	Not retained due to lack of effectiveness and land requirements.
	POTW	Aqueous streams are discharged to a POTW for treatment.	VOCs are effectively treated at POTWs to below NPDES discharge requirements.	Implementable, provided that water meets pretreatment limits.	Low to moderate.	Retained for further evaluation for groundwater.
	Surface water	Discharge of treated groundwater to nearby surface water body.	Effective though discharge to harbor or Lake Michigan may require additional treatment processes to remove inorganics.	Implementable, though it requires meeting the substantive requirements of an National Pollutant Discharge Elimination System (NPDES) permit.	Low to moderate.	Retained for further evaluation for treated groundwater.
	Reinjection	Reinjection of treated groundwater to the aquifer upgradient or side-gradient to the impacted area.	May increase the effectiveness of aquifer restoration due to increased flow rate through aquifer as a result of reinjection.	Implementable. Reinjected water would likely be required to meet drinking water MCLs or PRGs.	Low to moderate.	Retained for further evaluation for treated groundwater.
	Evaporation ponds	Surface impounds are used to contain treated or untreated wastewater or groundwater until it evaporates	Ponds would have to be very large to accommodate flow rate and allow time for sufficient volatilization. Air emissions of VOCs would not be controlled.	Not likely to be implementable due to air emissions and large land requirement.	Low to moderate.	Not retained due to air emissions and land requirements.

Note:
Highlighted technologies are screened from further consideration in the assembly of remedial action alternatives.
Effectiveness is the ability to perform as part of an overall alternative that can meet the objective under conditions and limitations that exist onsite.
Implementability is the likelihood that the process could be implemented as part of the remedial action plan under the physical, regulatory, technical, and schedule constraints.
Relative cost is for comparative purposes only and it is judged relative to the other processes and technologies that perform similar functions.

In Situ Thermal Desorption Implementation of in situ thermal desorption involves installation of wells followed by installation of heating elements into each well. Heat is applied to the aquifer by the heating element in close contact with the aquifer matrix. This differs from resistance heating as no current is passed through the matrix. Thermal conduction transfers heat away from the heated wells. Heated extraction wells are installed to collect vapors generated by the heating of the aquifer. The steam is collected and condensed. The condensation is treated and discharged while VOCs remain in the vapor phase which is treated and released. The cost to implement the in situ thermal desorption process option is moderate to high.

3.3.2 DNAPL Collection

The DNAPL collection response action, if implemented, could potentially use multiple process options. Active extraction could be useful for collecting mobile, easily extractable DNAPL while passive collection or periodic pumping of a collection "sump" could be more effective for residual DNAPL. Treatment and disposal options are likely limited to offsite incineration. The cost of DNAPL collection is low to moderate and is primarily dependent upon the volume of DNAPL recovered and the cost of disposal.

3.3.3 In Situ Soil Mixing

The soil mixing response action, if implemented, would combine a stabilizing amendment such as bentonite clay with a treatment amendment such as ZVI. Soil mixing would utilize large-diameter augers to mix the amendments with the DNAPL and native soils to stabilize the DNAPL while distributing the treatment amendment throughout the mixture. The combination lowers DNAPL mobility while providing treatment of the COCs. The cost of soil mixing is low to moderate and is primarily dependent on the depth to the DNAPL and the size of the DNAPL area.

3.4 Technology and Process Option Screening for Groundwater

Using the same methodology described in the preceding section, Table 3-1 presents the results of a qualitative comparison of technology types and process options available for groundwater remediation. The response actions and associated process options that were retained after screening for remediation of groundwater at the site include the following:

- No further action
- Institutional controls: deed restrictions, permits, and monitoring
- In situ treatment: chemical reduction, electrical resistance heating, thermal desorption, enhanced in situ bioremediation, natural attenuation
- Collection: vertical wells, horizontal wells
- Ex situ treatment: chemical oxidation, carbon adsorption, air stripping
- Discharge: POTW, surface water, reinjection

The rationale for selecting these process options is indicated in Table 3-1. The following sections highlight technologies where more detailed evaluation was necessary to distinguish between technologies or process options. These technologies include containment, in situ treatment, ex situ groundwater treatment, and groundwater discharge.

3.4.1 Containment

Containment alternatives for groundwater were considered as part of the evaluation process. Evaluated alternatives include hydraulic gradient control, sheet piling, slurry walls, and permeable reactive barriers. The findings of the RI indicate groundwater contamination from the OMC site is not discharging to Lake Michigan east of the site. In addition, groundwater analytical results indicate groundwater contamination related to the OMC site is not discharging to Waukegan Harbor. The CVOC migration velocities are very slow, and there is substantial natural attenuation occurring. As a result, the most important remedial objectives for groundwater are returning the groundwater to drinking water standards and preventing indoor exposures from volatilization from the plume.

As a result, hydraulic containment or passive reactive barrier technologies with the objective of preventing offsite migration are not currently needed to protect the harbor or lake and do not meet the more important objectives of groundwater restoration to drinking water standards. These technologies were not retained for inclusion in the groundwater remedial alternatives. Containment alternatives may be incorporated as a component of DNAPL remedial alternatives.

3.4.2 In Situ Treatment

In situ treatment process options that were evaluated in more detail include the following:

- In situ chemical oxidation
- In situ chemical reduction
- Permeable reactive barriers (passive treatment walls)
- Air sparging
- Enhanced reductive dechlorination
- In situ thermal desorption
- Electrical resistance heating

Each process option is presented in greater detail below. The process options of in situ chemical oxidation, reduction, enhanced reductive dechlorination, in situ thermal desorption, and electrical resistance heating have a relatively high cost and would be applied to the more concentrated portions of the plume. The process options of permeable reactive barriers and air sparging would be applied in combination with the other process options to the less concentrated portions of the plume as an additional treatment step.

In Situ Chemical Oxidation

This technology involves injection of a strong chemical oxidant (ozone, persulfate, permanganate, or peroxide) into the contaminant plume. The ensuing reaction then oxidizes the organic contaminants it contacts. The oxidation reaction can be highly exothermic with stronger oxidants like peroxide. The vapors and steam generated during the reaction could potentially migrate through underground utilities or piping. These concerns can be addressed by using a slightly weaker oxidant such as permanganate; however, permanganate solution and permanganate solid are a dark purple color. The potential for the oxidant to migrate along utility corridors could result in a discharge of dark purple water to nearby surface water bodies.

The implementation cost of in situ chemical oxidation (ISCO) is considered moderate for source areas. The cost to implement ISCO for the dissolved plume exceeding PRGs is considered high. This is largely the result of the high oxidant demand expected because the aquifer is under strongly reducing conditions with a high organic content of the soil and groundwater. This option was not retained for inclusion in the remedial alternatives due to costs and implementation concerns.

In Situ Chemical Reduction

The in situ chemical reduction (ISCR) process option involves delivering a chemical reducing agent to the subsurface to treat the contaminants. Reducing agents being evaluated include EHC®, Daramend®, and emulsified ZVI. All three reducing agents contain ZVI but vary in the size of the iron particles and the nature of the controlled-release carbon source. The emulsified ZVI is specifically designed to target DNAPL areas. The design of the ISCR amendments is to provide a carbon source to stimulate biological activity while the ZVI provides rapid dechlorination of the CVOCs. The cost of ISCR is estimated at low to moderate and is driven primarily by the longevity of the reducing agents in the subsurface and delivery methods. This option was retained for inclusion in the remedial alternatives.

Permeable Reactive Barriers

A permeable reactive barrier (PRB) is an in situ technology that is designed to passively intercept and remediate a groundwater plume. The PRB is commonly installed across the flow path of the plume, allowing the groundwater to move through the reactive zone under natural gradients. The reactive media, which commonly includes ZVI or other metals, compost, limestone, granular activated carbon (GAC), and/or zeolites, are selected based on the contaminant. The proper design of a PRB is highly dependent on a complete and accurate site characterization. Collection of hydrogeologic, geochemical, microbial, and geotechnical data along with the complete vertical and horizontal plume delineation are necessary to design a PRB to ultimately meet the goal of achieving PRGs downgradient of the barrier.

The main advantage of this system is that no pumping or aboveground treatment is required; the barrier acts passively after installation. There are no aboveground installed structures, so the area can be returned to productive use while the groundwater is being remediated.

Air Sparging

Air sparging involves injection of air into wells positioned at least 10 to 20 feet into the saturated zone. Sparged air moves through the saturated media by buoyancy, generally in the form of discrete, finger like channels, or, in the case of coarse sand and gravel, in the form of bubbles. Air sparging is used to remove dissolved CVOCs by in situ mass transfer (stripping), therefore, Henry’s Law constant is an important factor to consider when air sparging is used to treat solvents.

Depending on CVOC concentrations in groundwater, and associated vapor phase concentrations released to the vadose zone/atmosphere, soil vapor extraction may be required. In general, for lower concentration dissolved plumes, the concentration of CVOCs in the vapor phase is much less than National Institute of Occupational Safety and Health (NIOSH) or U.S. Occupational Safety and Health Administration (OSHA) standards, but may exceed USEPA vapor intrusion standards in some cases. Monitoring of shallow vadose zone pore gas is generally recommended as a precautionary measure if soil vapor extraction is not conducted.

Enhanced In Situ Bioremediation

Electron donors (hydrogen, lactate, food-grade oils, corn syrup, whey, etc.) are delivered to the subsurface within the target treatment zone to stimulate anaerobic biodegradation of chlorinated solvents by reductive dechlorination. Injection of the substrate would be performed using direct-push methods or permanently installed injection wells. The substrate addition would stimulate the native micro-organisms which in turn “consume” the contaminants generating methane/ethane/ethene and other byproducts. Injections would be performed periodically to sustain the biological community. The goal of the enhanced bioremediation alternative would be to reduce contaminant concentrations to levels that can be remediated to PRGs by MNA. The cost of this alternative is considered low to moderate. Enhanced reductive dechlorination was retained for inclusion into remedial alternatives. The results of an enhanced in situ bioremediation (EISB) pilot study (CH2M HILL, 2008b) performed in 2007 and 2008 indicate EISB is an effective groundwater treatment technology at the OMC site.

In Situ Thermal Desorption

In situ thermal desorption’s (ISTD’s) primary application uses thermal heating wells, along with heated extraction wells. Heat is applied to soil from a high temperature surface in contact with the soil. Thermal radiation and thermal conduction heat transfer are effective near the heating element. As a result, thermal conduction and convection expand into the soil volume. The ISTD process creates a zone of very high temperature (greater than 1,000°F) near the heaters, which can oxidize or pyrolize target constituents. A soil vapor extraction system is used to remove volatilized constituents.

ISTD raises the soil temperature within the treatment volume to the boiling point of water, generating steam in situ. This results in steam distillation of the contaminants. ISTD occurs as vapors are drawn into the hot regions in close proximity to heated extraction wells. The cost of ISTD is high, driven primarily by the cost of capital equipment, condensate treatment, and vapor treatment. ISTD was retained for inclusion in the remedial alternatives.

Electrical Resistance Heating

ERH operates under the principal that electrical current passing through a resistive component, such as soil, will generate heat. The amount of current which can be made to flow through a given soil type is a function of the voltage applied and the resistance of the soil. Several factors govern the resistance between adjacent Six-Phase Heating™ (SPH) electrodes including soil type, moisture content, and the distance between electrodes. Since distance and soil types are fixed components, current flow can be controlled by regulating soil moisture content and the applied voltage.

Electrical current is split into multiple (typically three or six) electrical phases for the electrical resistive heating of soil and groundwater. The electrical current is derived from a centrally located transformer and sent to each of the electrodes placed in the subsurface. Soil and groundwater are heated to appropriate temperatures, dependant upon soil type, allowing the volatilization of contaminants. Once soil contaminants are volatilized, they are removed from the subsurface media by a soil vapor extraction system, and treated above ground using conventional methods such as oxidation or adsorption.

By heating subsurface material to the boiling point of water, an in situ source of steam is created which strips contaminants from the soil. The steam serves two purposes. First, its physical action drives contaminants out of portions of the soil that tend to lock in the contaminants via capillary forces. Second, the steam acts as a carrier gas for the contaminants, enabling the contaminants to be swept out of the soil into the vacuum vent by increasing the permeability of the soil.

Thermocouples measure soil temperatures at multiple locations within the treatment area at varying depths. The system requires daily manual adjustments of the electrode voltage and SVE system vacuum. An onsite computer is used to adjust voltages on the transformer to maintain a consistent power input. ERH is a full-scale, batch, in situ technology.

Costs for ERH are moderate to high and are driven primarily by the cost of electricity and the area to be treated. ERH was retained for inclusion in the remedial alternatives.

3.4.3 Ex Situ Treatment

CVOCs are the primary contaminant expected to be present in extracted groundwater that will require treatment to discharge standards prior to reinjection or discharge to surface water. Iron and manganese may also be present in groundwater at elevated concentrations as a result of the reducing conditions in the aquifer. The reducing conditions result in the reduction of iron and manganese naturally present in the aquifer soil to soluble forms. Once these inorganics are no longer under reducing conditions, they would be expected to become oxidized back to their immobile forms. Removal of iron and manganese may be necessary prior to discharge to surface water

The most suitable process options identified for treatment of CVOCs are ultraviolet (UV)/oxidation, carbon adsorption (using GAC) and/or air stripping. The cost for ex situ treatment is moderate to high and is driven primarily by the cost of long-term O&M, utility costs, and capital equipment costs. UV/oxidation was retained primarily because of the presence of relatively high concentrations of vinyl chloride. Vinyl chloride, while easily air stripped, is not easily removed with GAC. If emissions from an air stripper require treatment for vinyl chloride, it may be more cost effective to use UV/oxidation because it destroys the vinyl chloride in the water phase. Each of these technologies was retained and will be evaluated further in the alternative development.

3.4.4 Discharge

Under the discharge response action, the process options of discharge of treated groundwater to the POTW, surface water (North Ditch, South Ditch, Waukegan Harbor) and re-infiltration are retained. Discharge to a surface water such as Lake Michigan or Waukegan Harbor generally has more stringent discharge limits, particularly for inorganics. Each of these discharge options will be evaluated in more detail in the alternative development.

SECTION 4

Alternative Descriptions

4.1 Introduction

The remedial technologies and process options that remain after screening for TCE DNAPL and groundwater media were assembled into a range of alternatives. The remedial alternatives were developed separately for TCE DNAPL and groundwater to allow for a wider range of alternatives and greater flexibility in selecting the recommended alternatives.

The specific details of the remedial components discussed for each alternative are intended to serve as representative examples to allow order-of-magnitude cost estimates. Other viable options within the same remedial technology that achieve the same objectives may be evaluated during remedial design activities for the site. The following sections provide a detailed description of each alternative. Table 4-1 summarizes the developed remedial alternatives.

4.2 DNAPL Alternative Descriptions

4.2.1 DNAPL Alternative 1—No Further Action

The objective of the DNAPL Alternative 1 (D1), the No Further Action Alternative, is to provide a baseline for comparison to other alternatives, as required by the NCP. Alternative D1 does not include any further remedial action for groundwater. It does not include monitoring or institutional controls.

4.2.2 DNAPL Alternative 2—Institutional Controls and Monitoring

The objective of DNAPL Alternative 2 (D2) is to rely on institutional controls to prevent exposure of residents or workers to DNAPL COCs and to use monitoring to evaluate whether exposures may be occurring. Institutional controls include well drilling restrictions to prevent exposure to DNAPL. A restrictive covenant would be placed on the OMC property deed that would specify that production wells cannot be installed within the DNAPL area. An institutional control would also be included to require use of subslab vapor control systems for new structures placed over, or in close proximity to, the DNAPL area.

Monitoring will include both the collection and analysis of soil gas and groundwater in the vicinity of the DNAPL area. Four soil gas wells will be installed by hand to a maximum depth of 3 feet around the perimeter of the DNAPL area. The total organic vapor levels in the soil gas will be monitored annually using a field organic vapor monitor (e.g., PID).

This alternative will also include annual groundwater sampling of eight monitoring wells at four downgradient locations (each location will consist of a shallow and deep well) to monitor potential changes in VOC concentrations, if any, over time. Groundwater samples will be analyzed for VOCs and the following MNA parameters:

- Dissolved oxygen

- Oxidation-reduction potential
- Chloride
- Carbon dioxide
- Manganese
- Total iron, ferrous iron, ferric iron
- Sulfate and sulfide sulfur
- Nitrate and nitrite nitrogen
- Alkalinity
- pH, temperature, specific conductance

The thickness of the DNAPL in each of the deep wells will also be measured prior to each annual sampling event.

4.2.3 DNAPL Alternative 3—Extraction, Onsite Collection, and Offsite Destruction

The objective of DNAPL Alternative 3 (D3) removal is to remove free-phase DNAPL to the extent practicable, resulting in a reduction of a secondary source of CVOCs to the groundwater. Previous investigations have shown that measurable TCE DNAPL is present just east of the former metal working area. Additional investigations to delineate the southwestern extent of the DNAPL (see Figure 2-1) will be performed as part of the post-building demolition activities.

The DNAPL removal system could be implemented as a standalone option or as a component of the groundwater extraction and treatment system. Designated DNAPL recovery systems would be installed in extraction wells where DNAPL has been identified during site investigation activities.

Implementation of the DNAPL recovery system would include installation of two 6-inch-diameter stainless steel well to a depth of 30 feet in the DNAPL area. A DNAPL recovery pump would then be installed at the base of the extraction wells. The DNAPL recovery pumps would be powered using several solar panels mounted nearby. Solar power is applicable as the DNAPL extraction pump will not operate continuously to allow time for the DNAPL to recover. The DNAPL would be collected in 55-gallon drums and temporarily placed in a secure small storage building. The storage area would comply with RCRA secondary containment requirements for hazardous waste. It is estimated that 55 gallons of DNAPL will be recovered every 1 month over a 5-year period and shipped offsite for hazardous waste incineration.

Monitoring for this alternative will include the monthly measurement of DNAPL thickness in monitoring wells and the extraction wells during the first 5 years of active extraction. In addition, annual groundwater sampling of eight monitoring wells for VOCs and MNA parameters and annual soil gas sampling will be conducted as described in Alternative D2.

4.2.4 DNAPL Alternative 4—In Situ Thermal Treatment

DNAPL Alternative 4 (D4) uses in situ thermal treatment to remove DNAPL and reduce CVOC concentrations in the DNAPL area. ISTD could be implemented exclusively for DNAPL treatment or as a component of a larger scale system designed to treat the dissolved phase VOC plume. Thermal treatment would be accomplished using thermal desorption in the TCE DNAPL area presented on Figure 2-1. Additional investigations to delineate the

TABLE 4-1
Remedial Alternative Development
OMC Plant 2

General Response Actions	Remedial Technology/Process Option	D1 – No Further Action	D2 – Institutional Controls and Monitoring	D3 – Extraction, Onsite Collection and Offsite Incineration	D4 – In Situ Thermal Treatment	D5 – In Situ Chemical Reduction Treatment	G1 – No Further Action	G2 – Institutional Controls and Monitored Natural Attenuation	G3a – Source Zone In Situ Chemical Reduction	G3b – Enhanced In Situ Bioremediation with Soluble Substrate	G3c – Enhanced In Situ Bioremediation with Food Grade Oil	G4a – Groundwater Collection and Treatment with Monitored Natural Attenuation	G4b – Groundwater Collection and Treatment to MCLs	G5 – In Situ Thermal Treatment	G6 – Permeable Reactive Barrier	G7 – Air Sparge Curtain
No Action																

southwestern extent of the DNAPL (see Figure 2-1) will be performed as part of the post-building demolition activities.

ISTD would use thermal wells, along with heated extraction wells. Heat would be applied to soil from a high temperature surface in contact with the soil. Thermal radiation and thermal conduction heat transfer would be effective near the heating element. As a result, thermal convection and conduction would occur in the soil volume. The ISTD process would create a zone of very high temperature (greater than 1,000°F) near the heaters, which can oxidize or pyrolize target constituents. ISTD would raise the soil temperature within the treatment volume to the boiling point of water, generating steam in situ. This would result in steam distillation of the contaminants. ISTD would occur as vapors are drawn into the hot regions in close proximity to heated extraction wells. An SVE system would be used to remove volatilized constituents. SVE off-gases would be condensed to separate the liquid and vapor phases. The liquid phase would be treated with oil separation and activated carbon prior to water discharge to Lake Michigan. The separated oil would be disposed of as hazardous waste for incineration. The vapor phase will be treated in a thermal oxidizer and scrubber or similar treatment system prior to discharge to the atmosphere. It is estimated that the treatment and system operation will be performed over a 2-year period and monitoring will continue for 10 years.

Monitoring for this alternative will include monthly soil gas sampling from four soil gas locations along the perimeter of the DNAPL area during the implementation of the thermal treatment, and annually following completion of the in situ treatment. In addition, annual groundwater sampling of eight monitoring wells for VOCs and MNA parameters will be conducted as described for Alternative D2.

4.2.5 DNAPL Alternative 5—In Situ Soil Mixing with In Situ Chemical Reduction

The objective of DNAPL Alternative 5 (D5) is to incorporate amendments via shallow soil mixing to treat and stabilize TCE DNAPL and increase the surface area of the TCE DNAPL available to micro-organisms for anaerobic biological reductive dechlorination or chemical reduction. The increased surface area also accelerates the dissolution of TCE DNAPL into the groundwater, allowing for more effective treatment by chemical reduction.

The technology involves mixing reactive media (ZVI) and stabilizing agents into soils using conventional soil mixing equipment. The ZVI would corrode in situ releasing hydrogen, which then results in chemical reductive dechlorination of the CVOCs. The stabilizing agent (typically bentonite clay) provides multiple benefits in the ZVI soil mixing that includes the following:

1. Reduces the torque needed to rotate the augers during the soil mixing.
2. Provides high viscosity delivery fluid necessary for suspension of the reactive media.
3. Reduces the permeability of the mixed soil so that the mass flux from any untreated residuals is greatly reduced.
4. Reduces inflow of competing electron acceptors (e.g., dissolved oxygen and nitrate).
5. Increases residence time for the reaction to proceed.

A bench-scale study (i.e., column testing) was conducted by CSU to demonstrate the effectiveness of the ZVI-bentonite to degrade site-specific COCs. The bench-scale study also included evaluating the effectiveness of iron from three different sources, the impact on treatment performance with the addition of sodium bicarbonate and cement, and the ability to improve post treatment soil strength with the use of cement.

The initial TCE concentration in soil was approximately 350 mg/kg. The results of the bench-scale study showed the following TCE concentration after 2 months and approximately 6 months of reactions time.

	After 2 months using 1% Iron	After 6 months using 1% Iron	After 2 months using 3% Iron	After 6 months using 3% Iron
GMA Iron	48 mg/kg	0.58 mg/kg	0.11 mg/kg	0.04 mg/kg
Peerless Iron	190 mg/kg	16 mg/kg	12 mg/kg	0.10 mg/kg
QMP Iron	216 mg/kg	154 mg/kg	89 mg/kg	0.7 mg/kg

The final report and addendum are provided in Appendix C. In general, ZVI from GMA achieved the fastest degradation of TCE, followed by Peerless, then QMP. Faster reaction kinetics was achieved by using 3 percent versus 1 percent iron. Although the test using 3 percent iron provided nearly 99 percent reduction in 6 months, the same contaminant mass reduction can be achieved with a 1 percent iron concentration level over a longer duration. Because time is not a driver on the site, 1 percent iron could be used in the full-scale; however, the initial TCE concentration of 350 mg/kg in the bench-scale test is less than the anticipated post-mixing TCE concentration in the target area of 2,500 mg/kg. Based on the results of the bench-scale study and the estimated TCE concentration in the target area, it will be assumed for the cost estimate that 2 percent ZVI from GMA and 1 percent bentonite will be used to treat the DNAPL areas.

Large-diameter (6 feet or greater) augers would be advanced to a target depth of 30 feet. Upon reaching the target depth, the amendments would be injected through the augers. The augers would be advanced and retracted through the DNAPL interval several times to ensure complete mixing. This process would be repeated until the entire area had been treated. Additional investigations to delineate the southwestern extent of the DNAPL (see Figure 2-1) will be performed as part of the post-building demolition activities.

Quarterly groundwater sampling of eight monitoring wells at four downgradient locations (locations will be nested with a shallow and deep well) would be performed to determine whether a dissolved phase plume was generated as a result of soil mixing and to monitor the changes in the plume, if any, over time. Groundwater samples will be analyzed for VOCs and the following MNA parameters:

- Dissolved oxygen
- Oxidation-reduction potential
- Chloride
- Carbon dioxide
- Manganese
- Total iron, ferrous iron, ferric iron
- Sulfate and sulfide sulfur
- Nitrate and nitrite nitrogen
- Alkalinity
- pH, temperature, specific conductance

4.3 Groundwater Alternative Descriptions

Five groundwater media alternatives were developed to provide a range of remedial actions for groundwater contamination. The remaining technologies were incorporated into at least one alternative.

4.3.1 Groundwater Alternative 1—No Further Action

The objective of the Groundwater Alternative 1 (G1), the No Further Action Alternative, is to provide a baseline for comparison to other alternatives, as required by the NCP. Alternative G1 does not include any further remedial action for groundwater. It does not include monitoring or institutional controls.

4.3.2 Groundwater Alternative 2—Institutional Controls and Monitored Natural Attenuation

The objective of Groundwater Alternative 2 (G2) is to rely on natural attenuation for remediation of the groundwater plume. Natural attenuation is the process by which contaminant concentrations are reduced by volatilization, dispersion, adsorption, and biodegradation. Based on the site groundwater data, anaerobic conditions are present in the groundwater below the source area and at the plume perimeter. There is evidence of substantial biological degradation of the CVOCs.

The main remedial components of G2 include the following:

- Institutional controls
- MNA

Institutional Controls

Institutional controls include well drilling restrictions to prevent exposure to contaminated groundwater. A restrictive covenant would be placed on the OMC property deed that would specify that production wells can not be installed within the plume or within areas in proximity to the plume that could affect plume migration. Restrictive covenants may also be necessary for properties south of the site if VOCs remain above the MCLs or USEPA Region 9 PRGs. An institutional control would also be included to require use of subslab vapor control systems for any new structures placed over, or in close proximity to, the plume area.

Monitored Natural Attenuation

MNA would be used to assess the degree of natural attenuation and allow estimates of the time necessary to reach PRGs. The lateral extents of groundwater CVOC concentrations exceeding PRGs are shown on Figure 2-3. If monitoring data indicate further spreading of the plume above remedial goals along with a potential for adverse effects on receptors, active restoration with one of the remaining alternatives (G3, G4, or G5) would be implemented.

The objective of the monitoring program would be to collect sufficient information to track the lateral and vertical extent of the VOC contaminant plume, monitor changes in concentrations, and provide additional natural attenuation parameters to evaluate biodegradation of the VOCs. The program would also allow assessment of continued releases from the source area.

The alternative includes development of a spreadsheet-based first-order decay rate natural attenuation model. This model would assist in development of a time estimate to reach PRGs.

The groundwater monitoring network for alternative G2 is assumed to include shallow and deep monitoring wells at 10 locations for a total of 20 monitoring wells. The monitoring wells will be sampled annually for 30 years and analyzed for VOCs and the following natural attenuation parameters:

- Dissolved oxygen
- Oxidation-reduction potential
- Chloride
- Carbon dioxide
- Manganese
- Total iron, ferrous iron, ferric iron
- Sulfate and sulfide sulfur
- Nitrate and nitrite nitrogen
- Alkalinity
- pH, temperature, specific conductance

4.3.3 Groundwater Alternative G3—Source Zone In Situ Treatment

The objective in the use of Groundwater Alternatives 3a, 3b, and 3c (G3a, G3b, and G3c) is to treat the VOC source areas and VOC groundwater plume (greater than 1 mg/L VOCs) in situ. In situ alternatives include in situ chemical reduction (G3a) and in situ bioremediation (G3b and G3c). Each alternative is presented below.

Groundwater Alternative G3a–In Situ Chemical Reduction

The objective in the use of Groundwater Alternative 3a (G3a) is to treat the VOC source areas and the VOC-contaminated groundwater plume (greater than 1 mg/L) by adding amendments to enhance existing anaerobic reducing conditions. The target treatment area is shown on Figure 2-2.

Insoluble chemical amendments (ZVI, carbon sources, or a combination) would be delivered to the aquifer in solid or slurry form. The amendments would create a zone of strongly reducing conditions, accelerating reductive dechlorination of the VOC contaminants. The addition of carbon sources can act as an enhancement to indigenous micro-organisms in the treatment zone, although this alternative is intended to rely primarily on abiotic chemical reduction.

The institutional controls and MNA components for alternative G3a are as described for Alternative G2; however, MNA monitoring for alternative G3a will be performed quarterly for the first 3 years of implementation followed by annual sampling.

The ISCR amendment would be injected into the subsurface as a slurry at a 0.25 percent soil-to-mass ratio. This ratio is based on average COC concentrations in areas of the plume exceeding 1 mg/L total CVOCs. Because only one injection would be performed, the amendment would be delivered to the subsurface using injection by direct-push methods. Injection points would be installed in a fence pattern perpendicular to the direction of groundwater flow. Injection points would be placed on 25-foot centers with rows of injection points spaced 100 feet apart. Approximately 139 injection points to a depth of 30 feet bgs are required to treat groundwater in the target treatment zone.

Following emplacement of the ISCR amendment, physical, chemical, and biological processes result in a strongly reducing environment. The emplaced ISCR amendment treats the COCs in groundwater migrating through the amendment barrier and in a zone of strongly reducing conditions extending out from the amendment barrier. As groundwater passes through the series of barriers, COCs are degraded or destroyed.

Groundwater Alternative G3b–Enhanced In Situ Bioremediation with Soluble Substrate

The objective in the use of Groundwater Alternative 3b (G3b) is to treat the VOC source areas and VOC-contaminated groundwater plume (greater than 1 mg/L VOCs) by adding a soluble organic substrate to stimulate the micro-organisms to metabolize the VOCs. The target treatment areas are shown on Figure 2-2.

Enhanced reductive dechlorination is a process in which indigenous or inoculated micro-organisms (for example, fungi, bacteria, and other microbes) degrade (metabolize) the VOCs, converting them to innocuous end products. Soluble nutrients or other amendments may be used to enhance reductive dechlorination and contaminant desorption from subsurface materials.

In the absence of oxygen (anaerobic conditions), the VOCs would be ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate would be converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, nitrogen gas would ultimately be produced.

Design of the full-scale injection will be based on the results of the pilot test performed in 2007 (see *Enhanced In Situ Bioremediation Pilot Study Report*, CH2M HILL, 2008b). Permanent injection wells will be installed in Source Areas 1, 2, 3, and 5. The injection well installed in Area 4 for the pilot test will be used for the full-scale operations. The Area 5 pilot test injection wells will be abandoned during building demolition, and new injection wells will need to be installed during full-scale implementation. Injection wells will not be installed within the DNAPL area in Source Area 5 which will be treated with soil mixing and ZVI addition. Injection well spacing will range from 12.5 feet to 30 feet depending on the source area. Shallow wells will be installed to a depth of 15 feet, with a 5-foot screen at a depth of 10 to 15 feet. Deep wells will be installed to a depth of 30 feet, with a 5-foot screen at a depth of 25 to 30 feet. The solution of soluble substrate and water will be pumped from a poly tank into a manifold capable of injecting up to eight injection locations simultaneously. During the pilot test, it was found that injection rates of up to 15 gallons per minute (gpm) were achieved per well.

Permanent polyvinyl chloride (PVC) injection wells with stainless steel screens will be installed in a barrier configuration to use natural advective transport as the mechanism to bring dissolved contaminants into contact with the amendments and allow the amendments to be transported with groundwater flow through the target treatment zone. The injection wells will be placed in a line perpendicular to the groundwater flow for the TTZ. It is expected that only a portion of the contaminant mass will be treated within the injection area and that treatment will continue as the contaminant mass is transported beyond the injection area through the TTZ. The number of barriers required for each source area varies between 1 and 6 and was based on the source area size, hydraulic gradient and conductivity, porosity, and the number of pore volume flushes recommended between each barrier.

Target EISB amendment injection concentrations were developed using site-specific groundwater VOC concentrations along with hydrogeologic data, geochemical data, and subsurface biological data. The target EISB amendment concentrations are designed to achieve and sustain conditions favorable to EISB. For the soluble substrate, pilot test data indicates that injections will be required approximately every 90 days to remain effective, with each injection event taking approximately 40 days to complete, based on an injection rate of approximately 10 gpm. This will require a total of 4 injections per year, over the course of 4 years, for a total of 16 injections. Each year of injection will require a total of approximately 112,000 pounds of sodium lactate and 2.6 million gallons of water. The 4-year duration is expected to result in TCE degradation of 90 percent or more based on the results of the pilot test in areas where substrate was measured. Achieving the very low MCL concentrations of TCE and its degradation products is expected to require up to 30 years during which progress would be monitored through sampling and analysis of groundwater.

Groundwater samples will be collected using low-flow purge techniques and analyzed for VOCs. In addition to VOCs, the monitoring parameters will be the same as those measured for Alternative G2.

Groundwater Alternative G3c–Enhanced In Situ Bioremediation with food grade oil.

The objective in the use of Groundwater Alternative 3c (G3c) is to treat the VOC source areas and VOC-contaminated groundwater plume (greater than 1 mg/L VOCs) by adding a food-grade oil substrate to stimulate the micro-organisms to metabolize the VOCs. The target treatment areas are shown on Figure 2-2. The treatment mechanism is the same as groundwater alternative G3b.

The institutional controls and MNA components are as described for Alternative 2.

EISB implementation will involve the injection of the selected food-grade oil emulsion into the shallow and deep intervals of the aquifer. An aqueous solution will be prepared onsite and injected into a series of closely spaced, 2-inch-diameter injection wells. Design of the full-scale injection will be based on the results of the pilot test performed in 2007. Permanent injection wells, rather than direct-push locations, will be installed in Source Areas 1, 2, 3, and 5. The injection well installed in Area 4 for the pilot test will be used for the full-scale operations. The injection wells installed in Area 5 for the pilot test will be abandoned during building demolition, and new injection wells will be installed for this area during full-scale implementation. Injection wells will not be installed within the DNAPL area in Source Area 5, which will be treated with a different technology. Injection well spacing will range from 15 feet to 30 feet depending on the source area. Shallow wells will be installed to a depth of 15 feet, with a 5-foot screen at a depth of 10 to 15 feet. Deep wells will be installed to a depth of 30 feet, with a 5-foot screen at a depth of 25 to 30 feet. The solution of soluble substrate and water will be pumped from a poly tank into a manifold capable of injecting up to eight injection locations simultaneously. During the pilot test, it was found that injection rates of up to 15 gpm were achieved per well.

Permanent injection wells will be installed in a barrier configuration to use natural advective transport as the mechanism to bring dissolved contaminants into contact with the amendments and be reductively dechlorinated. The food grade oil is not soluble and is not transported with groundwater flow. This is in contrast to the groundwater alternative G3b where the substrate is soluble and can be transported with groundwater flow. The injection wells will be placed in a line perpendicular to the groundwater flow for the TTZ. It is expected that only a portion of the contaminant mass will be treated within the injection area and that treatment will continue as the contaminant mass is transported beyond the injection area through the TTZ. The number of barriers required for each source area varied between 2 and 6 and was based on the source area size, hydraulic gradient and conductivity, porosity, and the number of pore volume flushes recommended between each barrier.

Target EISB amendment injection concentrations were developed using site-specific groundwater VOC concentrations along with hydrogeologic data, geochemical data, and subsurface biological data. The target EISB amendment concentrations are designed to achieve and sustain conditions favorable to EISB. For the food grade oil, injections would be required approximately every 2 years to remain effective, with each injection event taking approximately 47 days to complete, based on injection rate and amount of solution required for each well. This would require two injections to allow reductive dechlorination to proceed over the course of 4 years. Each injection event will require a total of approximately 660,000 pounds of food grade oil and 160,000 gallons of water.

Groundwater samples will be collected using low-flow purge techniques and analyzed for VOCs. In addition to VOCs, the monitoring parameters and number of wells sampled will be the same as those included for Alternative G2.

4.3.4 Groundwater Alternative G4—Groundwater Collection and Treatment

The objective in the use of Groundwater Alternatives 4a and 4b (G4a and G4b) is to collect and treat the VOC-contaminated groundwater plume ex situ. G4a and G4b are differentiated by the groundwater VOC concentration within the TTZ at which the collection and treatment system would be shut down. Extraction and treatment of the contaminated groundwater within the TTZ would continue with G4a to a point at which concentrations are significantly diminished. Further reductions in concentration to PRG levels would be achieved with MNA. Extraction and treatment of the contaminated groundwater plume within the TTZ would be continued with G4b, to reduce VOC concentration to levels at or below MCLs.

Groundwater Alternative G4a–Groundwater Collection and Treatment with Monitored Natural Attenuation

The main remedial components of G4a include the following:

- Institutional controls
- Groundwater collection and treatment
- MNA

The institutional controls and MNA are as described for G2.

The objective of this component is to treat the VOC-contaminated groundwater plumes exceeding 1 mg/L total VOCs as shown on Figure 2-3. The groundwater extraction treatment system would consist of extraction wells, extraction pumps, connecting piping, controls, treatment train, building, and discharge piping. The goal of groundwater collection and treatment would be to maximize mass removal of VOCs from the groundwater within a 10-year time frame.

Thirty 4-inch-diameter steel extraction wells would be installed in the TTZ with 100-foot grid spacing. The extraction wells would be screened from approximately 15 to 30 feet bgs. The selected screened interval will collect water from the shallow (higher permeability) and deep (lower permeability) groundwater zones equally without the need for two extraction wells at each grid node. Groundwater would be extracted at a rate of 4 gpm from each extraction well. Groundwater extraction pumps will have adjustable flow rates if monitoring data indicates higher flow rates are necessary. Following groundwater extraction, the contaminated groundwater will be piped to the onsite treatment system.

Groundwater treatment would consist of GAC with pre-treatment removal of iron. The treated groundwater would be discharged to surface water via an NPDES permit. Groundwater extraction would be continued until groundwater VOC concentrations reach a point where concentrations have significantly diminished. Further reductions in concentration to PRG levels would be achieved with MNA based on first-order decay modeling. Natural attenuation monitoring would be performed on an annual basis for 30 years.

Groundwater Alternative G4b–Groundwater Collection and Treatment to MCLs

The main remedial components of G4b include the following:

- Institutional controls
- Groundwater collection and treatment
- MNA

The institutional controls and MNA are as described for G2.

The objective in the use of this component is to treat the VOC-contaminated groundwater plumes exceeding 1 mg/L total VOCs as shown on Figure 2-3. The groundwater extraction treatment system would consist of extraction wells, extraction pumps, connecting piping, controls, treatment train, building, and discharge piping. The goal for groundwater collection and treatment would be to maximize mass removal of VOCs from the groundwater over a 20-year time frame.

Sixty 4-inch-diameter steel extraction wells would be installed in the TTZ with 100-foot grid spacing. The extraction wells would be screened from approximately 15 to 30 feet bgs. The selected screened interval will collect water from the shallow (higher permeability) and deep (lower permeability) groundwater zones equally without the need for two extraction wells at each grid node. Groundwater would be extracted at a rate of 4 gpm from each extraction well. Groundwater extraction pumps will have adjustable flow rates if monitoring data indicates higher flow rates are necessary. Following groundwater extraction, the contaminated groundwater will be piped to the onsite treatment system.

Groundwater treatment methods used would consist of GAC with pre-treatment removal of iron. The treated groundwater would be discharged to surface water via an NPDES permit. Groundwater extraction would be continued until groundwater VOC concentrations reach MCLs in the TTZ. Performance monitoring would be performed on an annual basis for 30 years.

4.3.5 Groundwater Alternative G5—In Situ Thermal Treatment

The objective of Groundwater Alternative 5 (G5) is to treat the source areas and dissolved VOC plume (concentrations greater than 1 mg/L) as shown on Figure 2-3.

Thermal wells would be used during ISTD, along with heated extraction wells. Heat would be applied to soil from a high-temperature surface in contact with the soil. Thermal radiation and thermal conduction heat transfer would be effective near the heating element. As a result, thermal convection and conduction would occur in the soil volume. The ISTD process would create a zone of very high temperature (exceeding 1,000°F) near the heaters, which can oxidize or pyrolize target constituents. An SVE system would be used to remove volatilized constituents. Treatment of SVE offgas is assumed to be needed to meet air permit limits.

ISTD would raise the soil temperature within the TTZ to the boiling point of water, generating steam in situ. This would result in steam distillation of the contaminants. ISTD would occur as vapors are drawn into the hot regions in close proximity to heated extraction wells.

Four-inch-diameter steel thermal and heated extraction wells would be installed from the top of grade to the base of the aquifer. Heated extraction wells will be ringed with thermal wells to maintain an inward gradient limiting the potential for migration of vapors outside the TTZ. Thermal monitoring points would be installed to measure the distribution of heat in the subsurface. The offgas collected would be piped to an onsite treatment system to remove COCs through thermal oxidation and scrubber prior to discharge to the atmosphere, if necessary. It is anticipated that 24 months would be required to implement and complete alternative G5.

The goal in the use of ISTD would be for the treatment of source zones to reduce concentrations of VOCs to levels amenable to MNA within a reasonable time frame. The MNA performance is as described for G2.

4.3.6 Groundwater Alternative G6—Permeable Reactive Barrier

The objective in the use of Groundwater Alternative 6 (G6) is to reduce the dissolved-phase VOC plume to PRG levels before CVOC-impacted groundwater migrates offsite. Alternative G6 is only intended to be used in combination with Alternatives G3b or G3c. The preliminary alignment of the proposed 800-foot-long and 30-foot-deep PRB is shown on Figure 4-1; it would be keyed 2 feet into the till confining unit. ZVI would be used as the reactive media used in the PRB to reductively dechlorinate the CVOCs in groundwater. The goal of the ZVI PRB would be to reduce the concentrations of dissolved contaminants to below the PRGs prior to the property boundary.

Based on a groundwater flow rate of 150 feet per year (ft/yr), influent vinyl chloride concentration of 2,200 µg/L, a treatment goal of 0.2 µg/L, and Environmental Technologies Inc. (ETI) vinyl chloride degradation rates, the ZVI PRB would be 1.5 feet thick in the upper unit of the aquifer (5 to 25 feet bgs) (ETI, 2008). The ZVI PRB would only be 0.5 feet thick in the lower unit of the aquifer based on a groundwater flow rate of 30 ft/yr and influent vinyl chloride concentration of 13,000 µg/L; the same treatment goal would be applied. Several construction methods are available to install a PRB, including bioslurry, continuous trenching, jetting, or deep soil mixing. This configuration assumes aa bioslurry method where sand would be used as a bulking agent to fill the entire volume of the excavated trench.

Monitoring wells would be installed upgradient and/or downgradient of the PRB to supplement the existing groundwater monitoring network and monitor groundwater chemistry, elevation, and flow.

4.3.7 Groundwater Alternative G7—Air Sparge Curtain

The objective of Groundwater Alternative 7 (G7) is to treat the dissolved phase VOC plume downgradient of the source area to PRGs before it migrates offsite. Alternative G7 is intended for use only with Alternatives G3b or G3c. The estimated location of the air sparge curtain is shown on Figure 4-1.

In order to maximize air contact with the plume, minimize disruption of surface and near-surface infrastructure, and simplify distribution manifolds/piping, the conceptual design for this alternative entails installation of a horizontal directional drilled (HDD) sparge well, approximately 1,000 feet long, with 700 feet of “screen” (slotted pipe). The well would be double ended, with the screen section installed at a depth of approximately 25 to 30 feet bgs, within the lower unit of the aquifer. Approximately 150 feet of entry and exit drilling is assumed for this installation (300 feet of casing in total). Monitoring wells would be installed upgradient and/or downgradient of the air sparging system to supplement the existing groundwater monitoring network and monitor groundwater chemistry, elevation, and flow.

SECTION 5
Detailed Analysis of Alternatives

5.1 Introduction

The detailed analysis of alternatives presents the relevant information needed to compare the remedial alternatives for the DNAPL and groundwater media. The detailed analysis of alternatives follows the development of alternatives and precedes the selection of a remedy. The selection of the remedy is conducted following the FS in the USEPA ROD.

Detailed analysis of alternatives consists of the following components:

- A detailed evaluation of each individual alternative against seven NCP evaluation criteria
- A comparative evaluation of alternatives to one another with respect to the seven evaluation criteria

The detailed evaluation is presented in table format. The comparative evaluation is presented in text and highlights the most important factors that distinguish alternatives from each other.

5.2 Evaluation Criteria

In accordance with the NCP, remedial actions must include the following:

- Be protective of human health and the environment.
- Attain applicable or relevant and appropriate requirements (ARARs) or provide grounds for invoking a waiver of ARARs that cannot be achieved.
- Be cost effective.
- Utilize permanent solutions and alternative treatment technologies or resource-recovery technologies to the maximum extent practicable.
- Satisfy the preference for treatment that reduces TMV as a principal element.

In addition, the NCP emphasizes long-term effectiveness and related considerations that include the following:

- The long-term uncertainties associated with land disposal.
- The goals, objectives, and requirements of the Solid Waste Disposal Act.
- The persistence, toxicity, and mobility of hazardous substances and their constituents, and their propensity to bioaccumulate.
- The short- and long-term potential for adverse health effects from human exposure.

- Long-term maintenance costs.
- The potential for future remedial action costs if the selected remedial action fails.
- The potential threat to human health and the environment associated with excavation, transportation, disposal, or containment.

Provisions of the NCP require that each alternative be evaluated against nine criteria listed in 40 CFR 300.430(e)(9). These criteria were published in the March 8, 1990 *Federal Register* (55 FR 8666) to provide grounds for comparison of the relative performance of the alternatives and to identify their advantages and disadvantages. This approach is intended to provide sufficient information to adequately compare the alternatives and to select the most appropriate alternative for implementation at the site as a remedial action. The evaluation criteria include the following:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of TMV through treatment
- Short-term effectiveness
- Implementability
- Cost
- Community acceptance
- State acceptance

The criteria are divided into three groups: threshold, balancing, and modifying criteria. Threshold criteria must be met by a particular alternative for it to be eligible for selection as a remedial action. There is little flexibility in meeting the threshold criteria—either they are met by a particular alternative, or that alternative is not considered acceptable. The two threshold criteria are overall protection of human health and the environment, and compliance with ARARs. If ARARs cannot be met, a waiver may be obtained in situations where one of the six exceptions listed in the NCP occur (see 40 CFR 300.430 (f)(1)(ii)(C)(1 to 6).

Unlike the threshold criteria, the five balancing criteria weigh the trade-offs between alternatives. A low rating on one balancing criterion can be compensated by a high rating on another. The five balancing criteria include the following:

- Long-term effectiveness and permanence
- Reduction of TMV through treatment
- Short-term effectiveness
- Implementability
- Cost

The modifying criteria are community and state acceptance. These are evaluated following public comment on the proposed plan and are used to modify the selection of the recommended alternative. The remaining seven evaluation criteria, encompassing both threshold and balancing criteria, are briefly described below.

5.2.1 Threshold Criteria

To be eligible for selection, an alternative must meet the two threshold criteria described below, or in the case of ARARs, must justify that a waiver is appropriate.

Overall Protection of Human Health and the Environment

Protectiveness is the primary requirement that remedial actions must meet under CERCLA. A remedy is protective if it adequately eliminates, reduces, or controls current and potential risks posed by the site through each exposure pathway. The assessment, with respect to this criterion, describes how the alternative achieves and maintains protection of human health and the environment.

Compliance with ARARs

Compliance with ARARs is one of the statutory requirements of remedy selection. ARARs are cleanup standards, standards of control, and other substantive environmental statutes or regulations which are either “applicable” or “relevant and appropriate” to the CERCLA cleanup action (42 United States Code [USC] 9621[d][2]). Applicable requirements address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at a CERCLA site. Relevant and appropriate requirements are those that while not applicable, address problems or situations sufficiently similar to those encountered at the CERCLA site and their use is well suited to environmental or technical factors at a particular site. The assessment, with respect to this criterion, describes how the alternative complies with ARARs or presents the rationale for waiving an ARAR. ARARs can be grouped into the following three categories:

- **Chemical-specific:** ARARs are health- or risk-based numerical values or methodologies which, when applied to site-specific conditions, establish the amount or concentration of a chemical that may remain in or be discharged to the environment.
- **Location-specific:** ARARs restrict the concentration of hazardous substances or the conduct of activities solely because they are in specific locations, such as floodplains, wetlands, historic places, and sensitive ecosystems or habitats.
- **Action-specific:** ARARs include technology- or activity-based requirements that set controls, limits, or restrictions on design performance of remedial actions or management of hazardous constituents.

The identification of ARARs was summarized in Section 2.1 and the analysis of the potential ARARs relative to the remediation of the OMC Plant 2 site are provided in Appendix A of the FS Report (CH2M HILL, 2006a).

5.2.2 Balancing Criteria

The five criteria listed below are used to weigh the trade-offs between alternatives.

Long-Term Effectiveness and Permanence

This criterion reflects CERCLA’s emphasis on implementing remedies that will ensure protection of human health and the environment in the long term as well as in the short term. The assessment of alternatives with respect to this criterion evaluates the residual risks at a site after completing a remedial action or enacting a no action alternative and includes evaluation of the adequacy and reliability of controls.

Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion addresses the statutory preference for remedies that employ treatment as a principal element. The assessment, with respect to this criterion, evaluates the anticipated performance of the specific treatment technologies an alternative may employ. The criterion is specific to evaluating only how treatment reduces TMV and does not address containment actions such as capping.

Short-Term Effectiveness

This criterion addresses short-term impacts of the alternatives. The assessment with respect to this criterion examines the effectiveness of alternatives in protecting human health and the environment (that is, minimizing any risks associated with an alternative) during the construction and implementation of a remedy until the response objectives have been met.

Implementability

The assessment with respect to this criterion evaluates the technical and administrative feasibility of the alternative and the availability of the goods and services needed for its implementation.

Cost

Cost encompasses all engineering, construction, and O&M costs incurred over the life of the project. The assessment with respect to this criterion is based on the estimated present worth of the costs for each alternative. Present worth is a method of evaluating expenditures such as construction and O&M that occur over different lengths of time. This allows costs for remedial alternatives to be compared by discounting all costs to the year that the alternative is implemented. The present worth of a project represents the amount of money, which if invested in the initial year of the remedy and disbursed as needed, would be sufficient to cover all costs associated with the remedial action. As stated in the RI/FS guidance document (USEPA, 1988b), these estimated costs are expected to provide an accuracy of plus 50 percent to minus 30 percent. Appendix A and B provide a breakdown of the cost estimate for each DNAPL and groundwater alternative, respectively.

The level of detail required to analyze each alternative with respect to the cost criteria depends on the nature and complexity of the site, the types of technologies and alternatives being considered, and other project-specific considerations. The analysis is conducted in sufficient detail to provide an understanding of the significant aspects of each alternative and to identify the uncertainties associated with the evaluation.

The cost estimates presented for each alternative have been developed strictly for comparing the alternatives. The final costs of the project and the resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, the implementation schedule, the firm selected for final engineering design, and other variables; therefore, final project costs will vary from the cost estimates. Because of these factors, project feasibility and funding needs must be reviewed carefully before specific financial decisions are made or project budgets are established to help ensure proper project evaluation and adequate funding.

The cost estimates are order-of-magnitude estimates having an intended accuracy range of plus 50 to minus 30 percent. The range applies only to the alternatives as they are described in Section 4 and does not account for changes in the scope of the alternatives. Selection of specific technologies or processes to configure remedial alternatives is intended not to limit flexibility during remedial design, but to provide a basis for preparing cost estimates. The specific details of remedial actions and cost estimates would be refined during final design.

5.3 Detailed Analysis of DNAPL Alternatives

5.3.1 Detailed Evaluation

The following alternatives for TCE DNAPL were developed and described in Section 4.4:

- Alternative D1—No Further Action
- Alternative D2—Institutional Controls and Monitoring
- Alternative D3—Extraction, Onsite Collection, and Offsite Destruction
- Alternative D4—In Situ Thermal Treatment
- Alternative D5—In Situ Chemical Reduction Treatment

These five alternatives were evaluated in detail using the seven evaluation criteria described in Section 5.2. The detailed evaluations for these DNAPL media alternatives are presented in Table 5-1 and apply to TCE DNAPL only. The remedial technologies retained are generally applicable to PCB DNAPL; however, additional technologies specific to the PCB DNAPL are currently being evaluated.

5.3.2 Comparative Analysis

Overall Protection of Human Health and the Environment

The RAOs for remediation of DNAPL at the OMC Plant 2 site include the following:

- Prevention of residential indoor inhalation of VOCs that presents an HI greater than 1 or an excess lifetime cancer risk (ELCR) greater than 1×10^{-4} to 1×10^{-6}.
- Prevention of construction worker exposure to groundwater, through contact, ingestion, or inhalation that presents an HI greater than 1 or an ELCR greater than 1×10^{-4} to 1×10^{-6}.
- Remediation of contamination in groundwater to concentrations below an HI greater than 1 or ELCR greater than 1×10^{-4} to 1×10^{-6}within a reasonable time frame.
- Remediation of DNAPL and groundwater within the DNAPL area to the extent practicable and minimize further migration of contaminants in groundwater.

The No Further Action Alternative is not considered protective because it does not include groundwater monitoring or institutional controls to prevent access to DNAPL. Future exposure to groundwater contaminated from TCE dissolving from the DNAPL would result in risks of 2×10^{-2} ELCR and an HI of 325. Also, future risks from vapor intrusion from groundwater into homes would be unabated at a risk of 6×10^{-4} ELCR and an HI of 3.

The remaining alternatives are considered protective because they all include, at a minimum, restrictive covenants on the property deeds to prevent groundwater use, groundwater monitoring to verify natural attenuation is occurring, and requirements for vapor control systems for buildings built over or near the DNAPL. Alternative D2 reduces the potential human exposure and slowly returns groundwater to PRGs, however, it is less protective since the migration and dissolution of DNAPL in groundwater could still occur.

Alternative D3 involves removal of the mobile DNAPL pool. It contributes to achieving the first three RAOs by slightly reducing a continuing source of VOCs to the groundwater; however, only the mobile DNAPL can be removed. Residual (non-pumpable) DNAPL will remain and continue to act as a source of VOCs to the groundwater. The great majority of the estimated 295,000 pounds of TCE in the DNAPL area would remain under this alternative.

Alternatives D4 and D5 are the most protective of human health and the environment as both mobile and residual DNAPL are addressed. In Alternative D4, DNAPL and groundwater in the DNAPL treatment zone are rapidly heated to the boiling point generating steam which in turn boils and strips the DNAPL from the subsurface. The offgas produced is then extracted using SVE and, if necessary, the condensate and vapor phase are treated above ground prior to discharge. Treatment can be completed approximately 2 years after system operation begins. In situ thermal desorption has achieved variable results at other sites, but typically 75 percent or more of the DNAPL mass can be removed with in situ thermal desorption.

In situ chemical reduction, Alternative D5, also aggressively addresses mobile and residual DNAPL resulting in protection of human health and the environment. Mobile and residual DNAPL in the treatment zone are stabilized in a clay matrix combined with ZVI. The ZVI provides accelerated reductive dechlorination of the TCE DNAPL while the clay limits dissolution or migration of untreated DNAPL into the groundwater. The advantage of Alternative D4 over alternative D5 is the potentially shorter treatment time required for treatment of DNAPL by Alternative D4. Also, the soil mixing component allows the soil to be homogenized and enable good contact between the ZVI reducing agent and the contaminated soil. A summary of the overall protectiveness of the alternatives is provided in the table below.

Overall Protection of Human Health and the Environment

Does Not Meet Criteria	Meets Criteria
D1	D2, D3, D4, D5

Compliance with ARARs

Appendix A of the FS Report (CH2M HILL, 2006a) presents a compilation of all the state and federal chemical-specific, location-specific, and action-specific ARARs considered for the OMC Plant 2 site. With the exception of Alternative D1, the DNAPL remedial alternatives meet ARARs. DNAPL treatment Alternatives D4 and D5 would meet ARARs in less time than Alternatives D2 and D3.

TABLE 5-1
Detailed Evaluation of DNAPL Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative D1 No Further Action	Alternative D2 Institutional Controls and Monitoring	Alternative D3 Extraction, Onsite Collection, and Offsite Destruction	Alternative D4 In-Situ Thermal Treatment	Alternative D5 In-Situ Chemical Reduction Treatment
1. Overall Protection of Human Health and the Environment.	▪ The DNAPL will continue to contribute to groundwater resulting in TCE, cis-1,2-DCE, and vinyl chloride continuing to persist in groundwater at concentrations exceeding the PRGs. If groundwater were used for drinking, risks would be 2×10^{-2} ELCR and an HI = 325, both well higher than the NCP risk range. Also, future risks from vapor intrusion from groundwater into homes would be unabated at 6×10^{-4} ELCR and HI = 3, also higher than the risk range. ▪ There is a potential for human exposure to DNAPL since no institutional controls are part of this alternative even though groundwater is not used for potable purposes in the area.	• The DNAPL will continue to contribute to groundwater resulting in TCE, cis-1,2-DCE, and vinyl chloride continuing to persist in groundwater at concentrations exceeding the PRGs. ▪ The potential for human exposure to DNAPL will be minimized through institutional controls that require vapor control systems below buildings and that do not allow use of onsite groundwater. Under this alternative, the institutional controls will be required to be in effect indefinitely. ▪ Future use of the groundwater supply will be limited due to the institutional controls.	▪ This alternative removes free-phase DNAPL to reduce the mass of DNAPL contributing to the dissolved phase groundwater plume. The proportion of the estimated 295,000 lbs of TCE DNAPL mass that can be removed by this alternative, however, is small (less than 10 percent or 29,500 lb) and as a result, it will have minimal effect on overall protection of human health and the environment. ▪ The potential for human exposure to residual DNAPL in the subsurface will also be minimized through institutional controls that require vapor control systems below buildings and that do not allow use of onsite groundwater. Under this alternative, the institutional controls will be required to be in effect for decades.	▪ This alternative is expected to reduce the mass of DNAPL by 75 percent or more, thus greatly reducing continued dissolution of TCE to groundwater and reducing the potential for risks from vapor intrusion into buildings. ▪ The potential for human exposure to DNAPL will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for years, though less time than alternatives D1, D2, or D3.	▪ This alternative is expected to reduce the mass of DNAPL 75 percent or more and reduce the permeability of the DNAPL area, thus greatly diminishing TCE mass flux to the groundwater and vapor emissions to overlying buildings. ▪ The potential for human exposure to DNAPL will be minimized through institutional controls and the reduction in mobility/mass of DNAPL. Under this alternative, the institutional controls will be required to be in effect for years, though less time than alternatives D1, D2, or D3.
2. Compliance with ARARs[a]	▪ Would meet ARARs when DNAPL contamination does not generate groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride that exceed groundwater PRGs. Under this alternative, exceedances may persist indefinitely.	▪ Would meet ARARs when DNAPL contamination does not result in groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride that exceed groundwater PRGs. Under this alternative, exceedances may persist indefinitely.	▪ Would meet ARARs when DNAPL contamination does not result in groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride that exceed groundwater PRGs. Under this alternative, exceedances may persist indefinitely.	▪ Would meet ARARs when DNAPL contamination does not result in groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride that exceed groundwater PRGs.	▪ Would meet ARARs when DNAPL contamination does not result in groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride that exceed groundwater PRGs.
3. Long-Term Effectiveness and Permanence					
(a) Magnitude of residual risks	▪ No significant change in risk because no action taken. Risk relating to dissolution of DNAPL into TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater exceeding groundwater PRGs would persist indefinitely.	▪ No significant change in risk because no action taken. Risk relating to dissolution of DNAPL into TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater exceeding groundwater PRGs would persist indefinitely.	▪ Since this option is applicable only for active collection and treatment of mobile DNAPL, long-term risks related to residual (non-pumpable) DNAPL will remain indefinitely.	▪ Thermal treatment will reduce the mobile and residual DNAPL mass reducing risks associated with the DNAPL. Residual risks associated with impacted groundwater will be addressed by the selected groundwater alternative.	▪ In situ chemical reduction via soil mixing will treat the mobile and residual DNAPL mass reducing risks associated with the DNAPL. Residual risks associated with impacted groundwater will be addressed by the selected groundwater alternative.
(b) Adequacy and reliability of controls	• Not applicable.	▪ Requires reliance on institutional controls for DNAPL area and groundwater. These controls may be necessary indefinitely under this alternative.	▪ Requires reliance on institutional controls for DNAPL area and groundwater. These controls may be necessary indefinitely under this alternative.	▪ Does not rely on controls specifically related to the DNAPL area.	▪ Does not rely on controls specifically related to the DNAPL area.
4. Reduction of Toxicity, Mobility, or Volume through Treatment					
(a) Treatment process used	• Not applicable.	▪ Natural attenuation only.	▪ Mobile DNAPL mass is reduced by extraction and disposal. Offsite disposal via incineration is the most likely treatment process.	▪ Mobile and residual DNAPL are treated by heating the subsurface, generating steam to volatilize the CVOCs. Offgas is extracted using SVE and separated into a liquid (i.e., water and oil) and vapor phase. The oils will be disposed of off site. The water will be treated onsite with carbon, and vapors will be treated with a thermal oxidizer and scrubber prior to discharge.	▪ Mobile and residual DNAPL is mixed with a bentonite clay combined with ZVI. The mixing ensures complete contact between the ZVI and DNAPL allowing degradation by ISCR. The clay reduces the permeability of the treated area so that the mass flux from any residual untreated TCE is reduced significantly.
(b) Degree and quantity of TMV reduction through Treatment	▪ Not applicable.	▪ Natural attenuation of DNAPL would take multiple decades.	▪ Mobile DNAPL would be targeted for extraction, residual (non-pumpable) DNAPL would remain in the treatment area. The total mass of TCE DNAPL removed is expected to be a small percent of the existing mass (i.e., less than 10 percent or 29,500 lb).	▪ Would remove an estimated 221,000 lbs or more of the 295,000 lbs of TCE estimated to be present in the DNAPL area. ▪ Activated carbon removes VOCs from the water by adsorption, which is reversible. The carbon can be regenerated through thermal treatment which destroys the CVOCs and is irreversible. ▪ SVE offgas will be treated with a thermal oxidizer, which destroys the CVOCs and	▪ Would remove an estimated 221,000 lbs or more of the 295,000 lbs of TCE estimated to be present in the DNAPL area. Would reduce the mass flux of any remaining TCE by several orders-of-magnitude.

TABLE 5-1
Detailed Evaluation of DNAPL Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative D1 No Further Action	Alternative D2 Institutional Controls and Monitoring	Alternative D3 Extraction, Onsite Collection, and Offsite Destruction	Alternative D4 In-Situ Thermal Treatment	Alternative D5 In-Situ Chemical Reduction Treatment
				is irreversible. ▪ Oils will be disposed of offsite and incinerated, which is irreversible.	
(c) Irreversibility of TMV reduction	▪ Not applicable.	▪ Natural degradation of VOCs is irreversible.	▪ Extraction and destruction of the DNAPL is irreversible.	▪ Volatilization, adsorption, and incineration of the VOCs are irreversible.	▪ Chemical reduction of the DNAPL is irreversible. ▪ The clay mixture must remain hydrated to stabilize the DNAPL.
(d) Type and quantity of treatment residuals	▪ None, no treatment included.	▪ None.	▪ Residual DNAPL would remain in the subsurface acting as a source of groundwater contamination.	▪ Residual groundwater contamination will be addressed by the selected groundwater alternative.	▪ The structural properties of the soil can be impacted. This can be addressed by the addition of cement in the mixture near the ground surface. ▪ DNAPL stabilized in the mixture is rapidly degraded leaving no residuals ▪ Residual groundwater contamination will be addressed by the selected groundwater alternative.
(e) Statutory preference for treatment as a principal element	▪ Preference not met for groundwater because no treatment included.	▪ Preference not met for DNAPL or groundwater because no treatment beyond natural attenuation included.	▪ Preference not met for all the DNAPL area because a portion of the DNAPL remains in situ.	▪ Preference met because DNAPL is treated.	▪ Preference met because DNAPL is treated.
5. Short-Term Effectiveness					
(a) Protection of workers during remedial action	▪ No remedial construction, so no risks to workers.	▪ Minimal risks to workers during installation of monitoring locations. Appropriate health and safety procedures must be followed.	▪ Moderate risks to workers during construction or operation of the extraction system due to potential contact with DNAPL. Appropriate health and safety procedures must be followed.	▪ Moderate risks to workers during construction or operation of the thermal treatment system due to electrical hookups at each well. Proper health and safety procedures must be followed during construction and operation. Building security would be a priority to prevent tampering.	▪ Moderate risks to workers during construction or operation of the mixing system due to the large equipment. Proper health and safety procedures must be followed during construction and operation. ▪ Risks to workers during soil mixing are present as a result of the potential generation and accumulation of hydrogen gas. Accumulation of hydrogen will be monitored to prevent explosive conditions and the health and safety plan would also specify additional measures. ▪ Monitoring would be necessary to determine if any DNAPL vapors are emitted.
(b) Protection of community during remedial action	▪ No remedial construction, so no short-term risks to community.	▪ No risks to the community during installation of monitoring locations.	▪ Minimal risks to the community during construction and extraction. Operation and maintenance activities consist of periodic transport of the DNAPL offsite. DNAPL containment area outside the building will be secured.	• Minimal risks to the community during construction and operation. Offgas treatment will be provided, as necessary, to meet the air permit discharge limits and protect the community from air emissions. The system will be installed primarily inside the building and produces little to no noise.	• Minimal risks to the community during construction and operation. DNAPL areas are not located near neighboring properties. Implementation of this alternative can be completed in several weeks.
(c) Environmental impacts of remedial action	▪ No remedial construction, so no environmental impacts.	▪ No environmental impacts during installation of monitoring locations..	▪ No environmental impacts during construction or operation of the system.	▪ No environmental impacts during construction or operation of the system.	▪ Minimal areas of the ground surface will be disturbed. Areas are currently paved and the facility is not operating.
(d) Time until RAOs are achieved	▪ Long-term attainment of groundwater RAOs will take decades to meet under this alternative. ▪ Other remaining RAOs are not met.	▪ Long-term attainment of groundwater RAOs will take decades to meet under this alternative. ▪ Other remaining RAOs are not met.	▪ Long-term attainment of groundwater RAOs will require decades to meet under this alternative.	▪ The RAO for DNAPL can be met in several years.	▪ The RAO for DNAPL can be met in several years.

TABLE 5-1
Detailed Evaluation of DNAPL Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative D1 No Further Action	Alternative D2 Institutional Controls and Monitoring	Alternative D3 Extraction, Onsite Collection, and Offsite Destruction	Alternative D4 In-Situ Thermal Treatment	Alternative D5 In-Situ Chemical Reduction Treatment
6. Implementability					
(a) Technical feasibility	▪ No impediments.	▪ No impediments	▪ No impediments.	▪ Technically feasible though effectiveness may be limited for DNAPL that has diffused into the underlying clay.	▪ Areas must be accessible to crane mounted equipment with no substantial overhead or underground obstructions. Effectiveness is accentuated by the soil mixing that allows homogenizing of soil to increase contact of ZVI and TCE and allows treatment of upper clay.
(b) Administrative feasibility	▪ No impediments.	▪ No impediments.	▪ No impediments are expected.	▪ The building must remain in place to house the treatment system, minimize infiltration of stormwater, and assist with SVE of offgas.	▪ Treatment area should remain undisturbed until ISCR treatment of DNAPL is completed.
(c) Availability of services and materials	▪ None needed.	▪ None needed.	▪ Necessary engineering services and materials readily available for installation and operation of extraction system.	▪ Necessary engineering services and materials are readily available for installation and operation of system.	▪ Necessary engineering services and materials are readily available for installation and operation of system.
7. Total Cost	Capital Cost $ 0	Capital Cost $ 150,000	Capital Cost $ 490,000	Capital Cost $ 7,190,000	Capital Cost $ 1,730,000
	O&M Cost $ 0	O&M Cost $ 1,640,000	O&M Cost $ 1,270,000	O&M Cost $ 2,880,000	O&M Cost $ 330,000
	Periodic Cost $ 90,000	Periodic Cost $ 90,000	Periodic Cost $ 90,000	Periodic Cost $ 30,000	Periodic Cost $ 30,000
	Total Present Worth Cost $ 30,000	Total Present Worth Cost $ 580,000	Total Present Worth Cost $ 1,160,000	Total Present Worth Cost $ 9,750,000	Total Present Worth Cost $ 1,980,000

A waste handling plan would be developed under Alternative D3 to meet RCRA- and IEPA-specific hazardous waste treatment, storage, and disposal ARARs. Air and condensate treatment for the emissions under Alternative D4 would be implemented to meet Clean Air Act and applicable IEPA-specific ARARs. The substantive requirements for obtaining an injection permit would be met for Alternative D4. A summary of the compliance with ARARs is provided in the table below.

Compliance with ARARs

Does Not Meet Criteria	Meets Criteria
D1	D2, D3, D4, D5

Long-Term Effectiveness and Permanence

The long-term effectiveness and permanence of the In Situ Thermal Treatment Alternative (D4) and the In Situ Chemical Reduction Alternative (D5) exceed the effectiveness and permanence of Alternative D3 because mobile and residual DNAPL are addressed. Alternative D3 removes minimal DNAPL, so the long-term risks are largely unchanged with this alternative.

Alternative D4 ranks similarly to D5 in terms of long-term effectiveness and permanence. Alternative D4 removes DNAPL from the majority of the subsurface. Alternative D5 has the advantage of homogenizing the soil to achieve good contact of ZVI with the contaminated soil while also adding clay to reduce the mass flux of any remaining untreated TCE by several orders of magnitude. The remaining alternatives, No Further Action (D1) and MNA (D2), are similar in their long-term effectiveness and permanence, which is significantly less than Alternatives D4 and D5 since natural processes are the only technology relied on to reduce DNAPL mass. Alternatives D1 and D2 also have long-term impacts to the community and the environment related to restrictions on possible site use and risk from existing exposure pathways. A summary of the relative ranking of alternatives is provided in the table below.

Long-Term Effectiveness and Permanence
Relative Ranking from Lowest to Highest

Lowest 0	1	2	3	Highest 4
D1, D2		D3	D4	D5

Reduction of Toxicity, Mobility, and Volume through Treatment

Alternatives D4 and D5 provide the greatest reduction of DNAPL volume and mobility and indirectly reducing the toxicity. Alternative D5 immediately reduces the mobility, while the heat generated by Alternative D4 may result in short-term increases in the mobility of the DNAPL. Alternative D4 reduces the volume of DNAPL by extraction of the vapor phase, while the ISCR component of Alternative D5 requires a longer period time to reduce the volume of DNAPL by degradation. Alternative D3 follows D4 and D5 in the reduction of mobility and volume of DNAPL. The extraction of the mobile DNAPL provides a rapid decrease in volume; however, a majority of the mass of residual DNAPL will remain in the subsurface where the toxicity is not reduced. Alternatives D1 and D2 do not reduce the toxicity, mobility, or volume of DNAPL due to the lack of active treatment and do not meet the statutory preference for treatment. A summary of the relative ranking of alternatives is provided in the table below.

Reduction of Toxicity, Mobility, and Volume through Treatment
Relative Ranking from Lowest to Highest

Lowest **0**	**1**	**2**	**3**	**Highest** **4**
D1, D2	D3		D4	D5

Short-Term Effectiveness

There are no additional risks associated with the actual construction and implementation of the No Further Action Alternative (D1) and the MNA Alternative (D2) because no remedial construction is undertaken. Alternatives D3, D4, and D5 have minimal to moderate effects with respect to the protection of workers during remedial construction, protection of the community during remedial action, and environmental effects of remedial action.

Alternative D3 has a relatively small potential to affect workers, the community, and the environment during installation of the extraction and collection system and during handling of the collected DNAPL during transportation for disposal. The potential for contact with the DNAPL is highest during installation of the extraction well, during handling of the DNAPL for disposal, and potentially during transportation of the DNAPL to the disposal facility. Some emissions of vapors during extraction well installation are unavoidable, though risks to public health would be minimized through the use of proper personal protective equipment, emission control measures, and air monitoring. Alternative D4, In Situ Thermal Treatment, has a much greater potential impact on workers because it has much more infrastructure and processes that will handle high concentration CVOCs and DNAPL. Alternative D5 has the greatest potential for risks to workers because the soil mixing of ZVI produces hydrogen gas that must be monitored to avoid explosive conditions. Alternative D5 must also include good erosion controls to minimize environmental impacts as a result of the soil mixing.

The short-term effectiveness with respect to the time until the RAOs are achieved is shortest for the In Situ Thermal Treatment Alternative (D4) and In Situ Soil Mixing Alternative (D5) because these alternatives actively reduce the mass of DNAPL. For Alternative D4, it is anticipated that removal of the DNAPL mass in the treatment zone could be accomplished in approximately 2 years after system startup. Alternative D5 will immediately stabilize the DNAPL mass and require approximately 2 years to achieve substantial treatment of the TCE DNAPL mass.

Alternatives D1, D2, and D3 will likely require more than 30 years to meet the RAOs for DNAPL, with Alternative D3 requiring slightly less time because the mobile DNAPL will have been extracted. A summary of the relative ranking of alternatives is provided in the table below.

Short-Term Effectiveness
Relative Ranking from Lowest to Highest

Lowest **0**	**1**	**2**	**3**	**Highest** **4**
D1, D2		D3, D4, D5		

Implementability

All alternatives can be implemented at the site, and no technical or administrative implementability problems are expected. For Alternative D5, the stabilized area will have limited strength and should remain undisturbed until sampling results indicate the DNAPL has been fully degraded. At that time, additional measures (e.g., addition of concrete) can be taken to improve the strength of the surface material.

Cost

A summary of the estimated costs for each of the DNAPL alternatives is presented in Table 5-1 and in more detail in Appendix A. The table breaks down the estimated capital, O&M, and present net worth cost.

The No Further Action Alternative has the least present worth cost, as the only task associated with this alternative is the 5-year review (assumed for 30 years).

The highest present worth cost would result from Alternative D4 at $ 9.75 million. The treatment requires extensive capital equipment and labor for construction. The next highest present worth cost would be incurred from Alternative D5, at $ 1.98 million to implement, followed by Alternative D3 at $ 1.16 million. Alternative D2 has the lowest cost ($580,000) of the alternatives, with the exception of the No Further Action Alternative (D1).

5.4 Detailed Analysis of Groundwater Alternatives

5.4.1 Detailed Evaluation

The following alternatives for groundwater were developed and described in Section 4:

- Alternative G1—No Further Action
- Alternative G2—Institutional Controls and Monitored Natural Attenuation
- Alternative G3a—In Situ Chemical Reduction
- Alternative G3b—Enhanced In Situ Bioremediation with soluble substrate
- Alternative G3c—Enhanced In Situ Bioremediation with food-grade oil
- Alternative G4a—Groundwater Collection and Treatment with Monitored Natural Attenuation
- Alternative G4b—Groundwater Collection and Treatment to MCLs
- Alternative G5—In Situ Thermal Treatment

- Alternative G6—Permeable Reactive Barrier
- Alternative G7—Air Sparge Curtain

These ten alternatives were evaluated in detail using the seven evaluation criteria described in Section 5.2. The detailed evaluations for these groundwater alternatives are presented in Table 5-2.

5.4.2 Comparative Analysis

Overall Protection of Human Health and the Environment

The RAOs for remediation of groundwater at the OMC Plant 2 site include the following:

- Prevention of residential indoor inhalation of VOCs that presents an HI greater than 1 or an ELCR greater than 1×10^{-4} to 1×10^{-6}.
- Prevention of construction worker exposure to groundwater, through contact, ingestion, or inhalation that presents an HI greater than 1 or an ELCR greater than 1×10^{-4} to 1×10^{-6}.
- Remediate contamination in groundwater to concentrations below an HI greater than 1 or ELCR greater than 1×10^{-4} to 1×10^{-6}within a reasonable time frame.
- Remediate DNAPL and groundwater within the DNAPL area to the extent practicable and minimize further migration of contaminants in groundwater.

The No Further Action Alternative is not considered protective because it does not include groundwater monitoring or institutional controls to prevent access to contaminated groundwater. Future exposure to groundwater would result in risks of 2×10^{-2} ELCR and an HI of 325. Also, future risks from vapor intrusion from groundwater into homes would be unabated at a risk of 6×10^{-4} ELCR and HI of 3.

The remaining alternatives are considered protective. Alternative G2, MNA with Institutional Controls, is considered protective because it includes restrictive covenants on the property deeds to prevent groundwater use and it includes groundwater monitoring to verify natural attenuation. Alternative G2 eliminates human contact and slowly returns groundwater to MCLs; however, it is less protective because the migration of CVOCs could still occur in the groundwater. Also, the volatilization of VOCs to indoor air would be controlled only through institutional controls that require vapor control systems.

Alternative G3a involves construction of multiple treatment zones comprised of a chemical reducing agent in a configuration perpendicular to groundwater flow. As groundwater flows through the treatment zone, the natural reductive dechlorination process is chemically accelerated. Alternative G3 achieves the first three RAOs over several years as the pore volume of contaminated groundwater pass through the treatment zones. The removal of the contaminant sources (contaminated soil and/or DNAPL) eliminates the influx of additional contaminated groundwater.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative G1 No Further Action	Alternative G2 MNA and Institutional Controls	Alternative G3a In-Situ Chemical Reduction (ISCR)	Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)	Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)	Alternative G4a Groundwater Collection and Treatment with MNA	Alternative G4b Groundwater Collection and Treatment to MCLs	Alternative G5 In-Situ Thermal Treatment	Alternative G6 Permeable Reactive Barrier	Alternative G7 Air Sparge Curtain
1. Overall Protection of Human Health and the Environment.	▪ TCE, cis-1,2-DCE, and vinyl chloride will continue to persist in groundwater at concentrations exceeding the PRGs. If groundwater were used for drinking, risks would be 2 x 10^{-2} ELCR and a HI = 325, both higher than the NCP risk range. Also future risks from vapor intrusion from groundwater into homes would be unabated at 6 x 10^{-4} ELCR and HI = 3, also higher than the risk range. ▪ Although groundwater is not currently used as a drinking water source, there is a potential for future human exposure to contaminated groundwater since no institutional controls are part of this alternative.	• TCE, cis-1,2-DCE, and vinyl chloride will continue to persist in groundwater at concentrations exceeding the PRGs. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls that require vapor control systems below buildings and that do not allow use of onsite groundwater. Under this alternative, the institutional controls will be required to be in effect for decades. ▪ Future use of the groundwater supply will be limited due to the institutional controls.	▪ This alternative reduces the groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater in suspected source areas and areas with the highest concentrations (>1 mg/L), thus reducing the timeframe to meet the PRGs. The total CVOC mass targeted for treatment is greater than 90 percent of the total mass present in groundwater. ▪ Treats both dissolved and adsorbed phases of contamination. Relatively small hotspots of DNAPL or very high dissolved phase CVOCs can be successfully treated ▪ MNA will be utilized for the remainder of the VOC plume which will take 10 to 30 years to achieve PRGs. ▪ The potential for human exposure to contaminated groundwater will also be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for 10 to 30 years. .	▪ This alternative reduces the groundwater concentrations of TCE, cis-1,2-DCE, and VC in groundwater in suspected source areas and areas with the highest concentrations (>1 mg/L), thus reducing the timeframe to meet the PRGs. The total CVOC mass targeted for treatment is greater than 90 percent of the total mass present in groundwater. ▪ Treats both dissolved and adsorbed phases of contamination. Relatively small hotspots of DNAPL or very high dissolved phase CVOCs can be successfully treated ▪ MNA will be utilized for the remainder of the VOC plume which will take 10 to 30 years to achieve PRGs. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for 10 to 30 years .	▪ This alternative reduces the groundwater concentrations of TCE, cis-1,2-DCE, and VC in groundwater in suspected source areas and areas with the highest concentrations (>1 mg/L), thus reducing the timeframe to meet the PRGs. The total CVOC mass targeted for treatment is greater than 90 percent of the total mass present in groundwater. ▪ Treats both dissolved and adsorbed phases of contamination. Relatively small hotspots of DNAPL or very high dissolved phase CVOCs can be successfully treated ▪ MNA will be utilized for the remainder of the VOC plume which will take 10 to 30 years to achieve PRGs. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for 10 to 30 years.	▪ This alternative reduces the groundwater concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater in suspected source areas and areas with the highest concentrations (>1 mg/L), thus reducing the timeframe to meet the PRGs. The total CVOC mass targeted for treatment is 90 percent or greater percent of the total mass present in groundwater. ▪ Aquifer flushing has poor effectiveness for treating small areas of DNAPL or areas of very high dissolved phase CVOCs. These areas are likely present but cannot be readily delineated. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for years to decades, though less time than Alternatives G1 and G2.	▪ This alternative actively reduces the concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater over the entire plume, thus reducing the timeframe to meet the PRGs. The total CVOC mass targeted for treatment is more than 90 percent or greater percent of the total mass present in groundwater. ▪ Aquifer flushing has poor effectiveness for treating small areas of DNAPL or areas of very high dissolved phase CVOCs. These areas are likely present but cannot be readily delineated. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for years though less time than Alternatives G1 and G2.	▪ This alternative actively reduces the concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater in areas of the plume where total CVOC concentrations exceed 1 mg/L. The total CVOC mass targeted for treatment is 95 percent or greater of the total mass present in groundwater. ▪ Treats both dissolved and adsorbed phases of contamination. Relatively small hotspots of DNAPL or very high dissolved phase CVOCs can be successfully treated. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative the institutional controls will be required to be in effect for years, though less time than alternatives G1 or G2.	▪ This alternative actively reduces the concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater to below the PRGs when combined with other alternatives. ▪ This alternative treats low dissolved phase CVOCs the areas of the plume before it migrates offsite. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for years though less time than if the other alternatives were used alone.	▪ This alternative actively reduces the concentrations of TCE, cis-1,2-DCE, and vinyl chloride in groundwater to below the PRGs when combined with other alternatives. ▪ This alternative treats low dissolved phase CVOCs the areas of the plume before it migrates offsite. ▪ The potential for human exposure to contaminated groundwater will be minimized through institutional controls. Under this alternative, the institutional controls will be required to be in effect for years though less time than if the other alternatives were used alone.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative G1 No Further Action	Alternative G2 MNA and Institutional Controls	Alternative G3a In-Situ Chemical Reduction (ISCR)	Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)	Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)	Alternative G4a Groundwater Collection and Treatment with MNA	Alternative G4b Groundwater Collection and Treatment to MCLs	Alternative G5 In-Situ Thermal Treatment	Alternative G6 Permeable Reactive Barrier	Alternative G7 Air Sparge Curtain
2. Compliance with ARARs	▪ Would meet ARARs when TCE, cis-1,2-DCE, vinyl chloride and arsenic contamination in groundwater do not result in concentrations that exceed groundwater PRGs. Under this alternative, this would take decades and may persist indefinitely if DNAPL is not treated.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater do not result in concentrations that exceed groundwater PRGs. Under this alternative, this would take greater than 30 years and may persist indefinitely if DNAPL is not treated.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater do not result in concentrations that exceed groundwater PRGs. ▪ The substantive requirements for an injection permit would be met prior to implementation of this alternative.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater do not result in concentrations that exceed groundwater PRGs. VOCs would remain above PRGs for 10 to 30 years. ▪ The substantive requirements for an injection permit would be met prior to implementation of this alternative.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater do not result in concentrations that exceed groundwater PRGs. VOCs would remain above PRGs for 10 to 30 years. ▪ The substantive requirements for an injection permit would be met prior to implementation of this alternative.	▪ Would meet ARARs when TCE, cis-1,2-DCE , and vinyl chloride contamination in groundwater does not result in concentrations that exceed groundwater PRGs. Pumping is expected to continue for 10 years under this alternative followed by MNA for much longer. ▪ The substantive requirements for an NPDES permit for discharge of treated groundwater would be met prior to implementation of this alternative.	▪ Would meet ARARs when TCE, cis-1,2-DCE , and vinyl chloride contamination in groundwater does not result in concentrations that exceed groundwater PRGs. Pumping is expected to continue for 20 years under this alternative. ▪ The substantive requirements for an NPDES permit for discharge of treated groundwater would be met prior to implementation of this alternative.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater does not result in concentrations than exceed PRGs. Thermal treatment is expected to continue for approximately 1 year followed by years of MNA.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater does not result in concentrations than exceed PRGs.	▪ Would meet ARARs when TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater does not result in concentrations than exceed PRGs.
3. Long-Term Effectiveness and Permanence										
(a) Magnitude of residual risks	▪ No significant change in risk because no action taken. Reduction in risk relating to TCE, cis-1,2- DCE, and vinyl chloride contamination in groundwater exceeding groundwater PRGs would occur slowly over decades.	▪ No significant change in risk because no action taken. Reduction in risk relating to TCE, cis-1,2-DCE, and vinyl chloride contamination in groundwater exceeding groundwater PRGs would occur slowly requiring more than 30 years.	▪ Risks related to ingestion of groundwater will remain for decades following in situ treatment. Risks related to volatilization of VOCs to indoor air are less likely to remain. ▪ Effectiveness is diminished because reducing agent is less able to be transported downgradient by groundwater to areas requiring treatment.	▪ Risks related to ingestion of groundwater will remain for decades following in situ treatment. Risks related to volatilization of VOCs to indoor air are less likely to remain. ▪ Effectiveness is enhanced because the biological substrate is soluble and can be transported by groundwater to downgradient areas requiring treatment.	▪ Risks related to ingestion of groundwater will remain for decades following in situ treatment. Risks related to volatilization of VOCs to indoor air are less likely to remain. ▪ Effectiveness is enhanced because the food oil substrate remains effective for up to 2 years without reinjection.	▪ Risks related to ingestion of groundwater will remain for decades once the groundwater collection system remediates the highest concentrations of CVOCs in groundwater. MNA remediation of the remaining plume is anticipated to take numerous additional years. Risks related to volatilization of VOCs to indoor air are less likely to remain following active groundwater collection and treatment.	▪ Risks related to ingestion of groundwater will remain for years once the groundwater collection system remediates CVOCs in groundwater to MCLs. MNA remediation of the remaining plume is anticipated to take numerous additional years. Risks related to volatilization of VOCs to indoor air are less likely to remain following active groundwater collection and treatment.	▪ Risks related to ingestion of groundwater will remain for decades once the groundwater in situ treatment system remediates the highest concentrations of CVOCs in groundwater. MNA remediation of the remaining plume is anticipated to take numerous additional years. Risks related to volatilization of VOCs to indoor air are less likely to remain following in situ treatment.	▪ Risks related to ingestion of onsite groundwater and related to volatilization of VOCs to indoor air onsite will remain for decades. ▪ Risks related to ingestion of offsite groundwater and related to volatilization of VOCs to indoor air offsite will be reduced.	▪ Risks related to ingestion of onsite groundwater and related to volatilization of VOCs to indoor air onsite will remain for decades. ▪ Risks related to ingestion of offsite groundwater and related to volatilization of VOCs to indoor air offsite will be reduced.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative G1 No Further Action	Alternative G2 MNA and Institutional Controls	Alternative G3a In-Situ Chemical Reduction (ISCR)	Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)	Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)	Alternative G4a Groundwater Collection and Treatment with MNA	Alternative G4b Groundwater Collection and Treatment to MCLs	Alternative G5 In-Situ Thermal Treatment	Alternative G6 Permeable Reactive Barrier	Alternative G7 Air Sparge Curtain
(b) Adequacy and reliability of controls	▪ Not applicable.	▪ Relies on institutional controls to prevent use of groundwater. Also requires installation and maintenance of vapor control systems for all buildings placed over the plume. The reliability of these systems is expected to be good if properly maintained. These controls will be necessary for more than 30 years this alternative.	▪ Relies on institutional controls to prevent use of groundwater. These controls may be necessary for 10 to 30 years under this alternative.	▪ Relies on institutional controls to prevent use of groundwater. These controls will be necessary for 10 to 30 years under this alternative.	▪ Relies on institutional controls to prevent use of groundwater. These controls will be necessary for 10 to 30years under this alternative.	▪ Relies on institutional controls to prevent use of groundwater during remediation. These controls will be necessary for 10 to 30 years under this alternative.	▪ Relies on institutional controls to prevent use of groundwater during remediation.	▪ Relies on institutional controls to prevent use of groundwater during remediation.	▪ Relies on institutional controls to prevent use of groundwater during remediation.	▪ Relies on institutional controls to prevent use of groundwater during remediation.
4. Reduction of Toxicity, Mobility, or Volume through Treatment										
(a) Treatment process used	• Not applicable.	• Natural attenuation only.	• TCE, cis-1,2-DCE, and vinyl chloride concentrations are reduced as contaminated groundwater flows through the treatment barriers. Reduction in concentrations take place through chemically accelerated reductive dechlorination.	▪ TCE, cis-1,2-DCE, and vinyl chloride concentrations are reduced as the native biomass is enhanced. Reductions in CVOC concentrations take place through biologically accelerated reductive dechlorination.	▪ TCE, cis-1,2-DCE, and vinyl chloride concentrations are reduced as the native biomass is enhanced. Reductions in CVOC concentrations take place through biologically accelerated reductive dechlorination.	▪ This alternative will extract groundwater in areas of the plume exceeding 1 mg/L total CVOCs and pump the water to the onsite treatment system. ▪ The onsite treatment system will remove CVOCs using GAC.	▪ Will extract groundwater in areas of the plume exceeding compound-specific MCL and pump the water to the onsite treatment system. ▪ VOCs would be treated using GAC.	▪ Will treat contaminated groundwater by heating the subsurface generating steam to volatilize the CVOCs. Offgas is extracted using SVE and, if necessary, treated prior to discharge.	▪ TCE, cis-1,2-DCE, and vinyl chloride concentrations are reduced as contaminated groundwater flows through the treatment barriers. Reductions in concentrations take place through reductive dechlorination.	▪ Will treat contaminated groundwater by adding high volume of air to the subsurface volatilizing the CVOCs. Offgas may be extracted using SVE and, if necessary, treated prior to discharge.
(b) Degree and quantity of TMV reduction through treatment	▪ Not applicable.	▪ Reduction of CVOC concentrations to PRGs using natural attenuation alone would take more than 30 years.	▪ Groundwater with total CVOC concentrations greater than 1 mg/L would be targeted. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 12,600 lbs would be partially to completely dechlorinated as groundwater comes into contact with the treatment barriers.	▪ Groundwater with total CVOC concentrations greater than 1 mg/L would be targeted. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 12,600 lbs would be partially to completely dechlorinated as groundwater came into contact with the treatment zones.	▪ Groundwater with total CVOC concentrations greater than 1 mg/L would be targeted. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 12,600 lbs would be partially to completely dechlorinated as groundwater came into contact with the treatment zones.	▪ Groundwater with total CVOC concentrations greater than 1 mg/L would be targeted for extraction and treatment. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 12,600 lbs would be collected and treated.	▪ Would remove VOCs in the groundwater. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 13,000 lbs would be collected and treated.	▪ Would remove a majority of the CVOCs from the groundwater. An estimated CVOC (TCE, cis-1,2-DCE, and vinyl chloride) mass of 12,600 lbs would be destroyed. ▪ MNA would treat the remaining CVOCs over a period of years.	▪ The residual CVOCs resulting from treatment with other alternatives (ie. groundwater with low dissolved phase CVOCs) would be targeted. ▪ CVOCs would be completely dechlorinated as groundwater came in contract with the barrier.	▪ The residual CVOCs resulting from treatment with other alternatives (i.e., groundwater with low dissolved phase CVOCs) would be targeted. ▪ CVOCs would be partially or completely volatilized as groundwater came in contract with the treatment zone.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative G1 No Further Action	Alternative G2 MNA and Institutional Controls	Alternative G3a In-Situ Chemical Reduction (ISCR)	Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)	Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)	Alternative G4a Groundwater Collection and Treatment with MNA	Alternative G4b Groundwater Collection and Treatment to MCLs	Alternative G5 In-Situ Thermal Treatment	Alternative G6 Permeable Reactive Barrier	Alternative G7 Air Sparge Curtain
(c) Irreversibility of TMV reduction	• Not applicable.	• Natural degradation of VOCs is irreversible.	• Chemical reduction and accelerated biodegradation of the VOCs is irreversible.	• Enhanced biodegradation of VOCs is irreversible.	▪ Enhanced biodegradation of VOCs is irreversible.	▪ Activated carbon removes the VOCs from the extracted groundwater by adsorption, which is reversible. However activated carbon will be re-generated through incineration which destroys the CVOCs and is irreversible. ▪ Natural biodegradation of the remaining VOCs in the plume is irreversible.	▪ Activated carbon removes the VOCs from the extracted groundwater by adsorption, which is reversible. However activated carbon will be re-generated through incineration which destroys the CVOCs and is irreversible.	▪ Volatilization of the VOCs from the groundwater and biological treatment of the VOCs in the groundwater is irreversible. The SVE off gases would be treated either through catalytic oxidation, which is irreversible, or through GAC which is irreversible when the GAC is regenerated.	▪ Reductive dechlorination is irreversible.	▪ Volatilization of the VOCs from the groundwater is irreversible. The SVE off gases would be treated either through catalytic oxidation, which is irreversible, or through GAC which is irreversible when the GAC is regenerated.
(d) Type and quantity of treatment residuals	▪ None, because no treatment included.	▪ None.	▪ None.	▪ None.	▪ None.	▪ About 40,000 lbs/year of granular activated carbon is generated as a result of treatment.	▪ About 40,000 lbs/year of granular activated carbon is generated as a result of treatment.	▪ Small quantities of condensate will be generated during thermal treatment. Activated carbon may be generated if GAC is used for treatment of SVE off gases.	▪ None.	▪ Small quantities of condensate will be generated during thermal treatment. Activated carbon may be generated if GAC is used for treatment of SVE off gases.
(e) Statutory preference for treatment as a principal element	▪ Preference not met for groundwater because no treatment included.	▪ Preference not met for groundwater because no treatment beyond natural attenuation included.	▪ Preference met for groundwater because treatment occurs in-situ.	▪ Preference met for groundwater because treatment occurs in-situ.	▪ Preference met for groundwater because treatment occurs in-situ.	▪ Preference met for groundwater because treatment occurs at the onsite treatment plant.	▪ Preference met for groundwater because VOCs are treated.	▪ Preference met for groundwater because VOCs are treated.	▪ Preference met for groundwater because treatment occurs in-situ.	▪ Preference met for groundwater because VOCs are treated.
5. Short-Term Effectiveness										
(a) Protection of workers during remedial action	▪ No remedial construction, so no risks to workers.	▪ Limited risk to drillers during installation of monitoring wells.	▪ Risks to workers during construction or operation of the injection system are present as a result of the potential generation and accumulation of hydrogen gas. Accumulation of hydrogen will be monitored to prevent explosive conditions in and near injection wells. The health and safety plan would also specify additional measures such as use of non-sparking tools near the wells.	▪ No risk to workers during injection since EISB amendments are non-hazardous. ▪ No risks to workers during MNA monitoring.	▪ No risk to workers during injection since EISB amendments are non-hazardous. ▪ No risks to workers during MNA monitoring.	▪ Minimal risks to workers during construction or operation of the pumping system. Proper health and safety procedures must be followed during construction and operation.	▪ Minimal risks to workers during construction or operation of the pumping system. Proper health and safety procedures must be followed during construction and operation.	▪ Moderate risks to workers during construction or operation of the thermal treatment system due to electrical hookups at each well. Proper health and safety procedures must be followed during construction and operation. Building security would be a priority to prevent tampering.	▪ Minimal risks to workers during construction. Proper health and safety procedures must be followed during construction.	▪ Minimal risks to workers during construction. Proper health and safety procedures must be followed during construction.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	Alternative G1 No Further Action	Alternative G2 MNA and Institutional Controls	Alternative G3a In-Situ Chemical Reduction (ISCR)	Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)	Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)	Alternative G4a Groundwater Collection and Treatment with MNA	Alternative G4b Groundwater Collection and Treatment to MCLs	Alternative G5 In-Situ Thermal Treatment	Alternative G6 Permeable Reactive Barrier	Alternative G7 Air Sparge Curtain
			▪ Injected compounds pose little to no contact risk to implementation staff.							
(b) Protection of community during remedial action	▪ No remedial construction, so no short-term risks to community.	▪ No remedial construction, so no short-term risks to community.	▪ Minimal risks to the community during construction and injection. A majority of the work would be conducted inside the building. Operation and maintenance activities consist of periodic groundwater sampling posing little to no risk to the community.	▪ Minimal risks to the community during construction and injection. A majority of the work would be conducted inside the building. Operation and maintenance activities consist of periodic groundwater sampling posing little to no risk to the community.	▪ Minimal risks to the community during construction and injection. A majority of the work would be conducted inside the building. Operation and maintenance activities consist of periodic groundwater sampling posing little to no risk to the community.	• Minimal risks to community during construction and operation of the system. For noise, equipment will be housed within a building and will be designed to reduce noise levels.	• Minimal risks to community during construction and operation of the system. For noise, equipment will be housed within a building and will be designed to reduce noise levels.	• Minimal risks to the community during construction and operation. The system will be installed primarily inside the building and produces little to no noise.	• Minimal risks to the community during construction.	• Minimal risks to the community during construction and operation. The system will be installed primarily inside the building and produces little to no noise.
(c) Environmental impacts of remedial action	▪ No remedial construction, so no environmental impacts.	▪ No remedial construction, so no environmental impacts.	▪ Injection of ZVI results in reducing conditions in the groundwater. This in turn results in elevated levels of iron and manganese and may cause arsenic levels to increase in groundwater. The expected iron plumes will need to be closely monitored so that they do not increase to the point that they could discharge to the harbor. If iron plumes do discharge to harbor, the iron would oxidize at the harbor steel sheet piling walls, producing an orange-brown iron precipitate.	▪ Injection of substrates into groundwater results in reducing conditions in the groundwater. This in turn results in elevated levels of iron and manganese and may cause arsenic levels to increase in groundwater. The expected iron plumes will need to be closely monitored so that they do not increase to the point that they could discharge to the harbor. If iron plumes do discharge to harbor, the iron would oxidize at the harbor steel sheet piling walls, producing an orange-brown iron precipitate.	▪ Injection of substrates into groundwater results in reducing conditions in the groundwater. This in turn results in elevated levels of iron and manganese and may cause arsenic levels to increase in groundwater. The expected iron plumes will need to be closely monitored so that they do not increase to the point that they could discharge to the harbor. If iron plumes do discharge to harbor, the iron would oxidize at the harbor steel sheet piling walls, producing an orange-brown iron precipitate.	▪ No environmental impacts during construction or operations of the system. Onsite discharge via reinjection or to the harbor would meet all discharge limits to prevent risks to human health and aquatic life.	▪ No environmental impacts during construction or operations of the system. Onsite discharge via reinjection or to the harbor would meet all discharge limits to prevent risks to human health and aquatic life.	▪ No environmental impacts during construction or operation of the system.	▪ Injection of ZVI results in reducing conditions in the groundwater. This in turn results in elevated levels of iron and manganese and may cause arsenic levels to increase in groundwater. The expected iron plumes will need to be closely monitored so that they do not increase to the point that they could discharge to the harbor. If iron plumes do discharge to harbor, the iron would oxidize at the harbor steel sheet piling walls, producing an orange-brown iron precipitate.	▪ No environmental impacts during construction or operation of the system.
(d) Time until RAOs are achieved	▪ Long-term attainment of groundwater RAOs will take decades to meet under this alternative. ▪ Other remaining RAOs are not met.	▪ Long-term attainment of groundwater RAOs will take greater than 30 years to meet under this alternative.	▪ Long-term attainment of groundwater RAOs will require 10 to 30 years.	▪ Long-term attainment of groundwater RAOs will require 10 to 30 years.	▪ Long-term attainment of groundwater RAOs will require 10 to 30 years.	The RAO for treating groundwater to MCLs will be achieved in years to decades.	The RAO for treating groundwater to below the PRGs will not be achieved for many years.	▪ The RAO for treating groundwater to PRGs will require years to decades.	▪ Long-term attainment of groundwater RAOs will require years to decades.	▪ Long-term attainment of groundwater RAOs will require years to decades.

TABLE 5-2
Detailed Evaluation of Groundwater Alternatives
OMC Plant 2

Alternative Description: Criterion	**Alternative G1 No Further Action**	**Alternative G2 MNA and Institutional Controls**	**Alternative G3a In-Situ Chemical Reduction (ISCR)**	**Alternative G3b Enhanced In Situ Bioremediation with a Soluble Substrate (EISB)**	**Alternative G3c Enhanced In Situ Bioremediation with a Food Grade Oil (EISB)**	**Alternative G4a Groundwater Collection and Treatment with MNA**	**Alternative G4b Groundwater Collection and Treatment to MCLs**	**Alternative G5 In-Situ Thermal Treatment**	**Alternative G6 Permeable Reactive Barrier**	**Alternative G7 Air Sparge Curtain**
6. Implementability										
(a) Technical feasibility	▪ No impediments.	▪ No impediments	▪ Radius of influence for injection of insoluble amendments may be limited due to aquifer pore size	▪ Pilot testing to establish effectiveness and dosage of amendment was completed and EISB with soluble substrate was deemed effective.	▪ Pilot testing to establish effectiveness and dosage of amendment was completed and EISB with Food Grade Oil was deemed effective.	▪ No impediments.	▪ No impediments.	▪ No impediments.	▪ Presence of multiple underground utilities will impact the installation.	▪ Presence of multiple underground utilities will impact the installation.
(b) Administrative feasibility	▪ No impediments.	▪ No impediments.	▪ No impediments are expected.	▪ No impediments are expected.	▪ No impediments are expected.	▪ The substantive requirements for an NPDES discharge to the harbor or via reinjection will be met. The building must remain in-place to house the treatment system and extraction wells placed through the floor.	▪ The substantive requirements for discharge to the POTW will be met. The building must remain in-place to house the treatment system and extraction wells placed through the floor.	▪ No impediments are expected.	▪ No impediments are expected.	▪ No impediments are expected.
(c) Availability of services and materials	▪ None needed.	▪ None needed.	▪ Necessary engineering services and materials readily available for installation and operation of injection system.	▪ Necessary engineering services and materials readily available for installation and operation of injection system.	▪ Necessary engineering services and materials readily available for installation and operation of injection system.	▪ Necessary engineering services and materials readily available for installation and operation of system.	▪ Necessary engineering services and materials readily available for installation and operation of system.	▪ Necessary engineering services and materials are readily available for installation and operation of system.	▪ Necessary engineering services and materials are readily available for installation and operation of injection system.	▪ Necessary engineering services and materials are readily available for installation and operation of injection system.
7. Total Cost	Capital Cost $ 0 O&M Cost $ 0 Periodic Cost $90,000 Total Present Worth Cost $30,000	Capital Cost $ 130,000 O&M Cost $ 2,170,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 1,060,000	Capital Cost $ 8,300,000 O&M Cost $ 2,890,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 9,610,000	Capital Cost $ 3,640,000 O&M Cost $ 6,740,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 8,300,000	Capital Cost $ 5,410,000 O&M Cost $ 8,150,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 11,240,000	Capital Cost $ 3,720,000 O&M Cost $ 6,930,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 8,040,000	Capital Cost $ 4,450,000 O&M Cost $ 12,030,000 Periodic Cost $ 90,000 Total Present Worth Cost $ 10,600,000	Capital Cost $15,480,000 O&M Cost $ 24,870,000 Periodic Cost $ 30,000 Total Present Worth Cost $ 37,840,000	Capital Cost $ 6,080,000 O&M Cost $ 340,000 Periodic Cost $ 0 Total Present Worth Cost $ 6,220,000	Capital Cost $ 790,000 O&M Cost $ 3,980,000 Periodic Cost $ 0 Total Present Worth Cost $ 2,430,000

Alternatives G3b and G3c achieve the first three RAOs over several years by injection of biological amendments resulting in enhancement of the native biomass present in the aquifer. The enhanced biomass accelerates the natural reductive dechlorination process. Alternatives G6 and G7 increase the ability of G3b and G3c to achieve RAOs before offsite migration, though they do not help achieve RAOs onsite.

Under Alternatives G3b and G3c, biological amendments are injected into the groundwater; however, with Alternative G3b, the biological amendment is soluble and can be transported by the advection of the groundwater enhancing the biomass as it travels rather than being stationary and requiring the groundwater to pass through a barrier as in Alternative G3a and G3c. As a result, Alternative G3b is considered more protective than Alternative G3a or G3c.

Alternatives G4a and G4b both address the first three RAOs by extracting contaminated groundwater and treating it using an onsite treatment system. Alternative G4b includes a larger network of extraction wells to remediate groundwater to MCLs, while alternative G4a is intended to treat only the more contaminated groundwater (greater than 1 mg/L CVOCs) to levels amenable to MNA. Alternative G4b will achieve the RAOs in a shorter period of time than Alternative G4a. Alternatives G4a and G4b are considered somewhat less protective than G3a and G3b because they rely only on aquifer flushing to reduce concentrations, whereas in situ treatment treats both the dissolved and adsorbed phases of contamination. Relatively small hotspots of DNAPL or very high dissolved phase CVOCs are more likely to be successfully treated under Alternatives G3a and G3b than with aquifer flushing of Alternatives G4a and G4b.

Alternative G5 addresses all four RAOs by rapidly heating groundwater to the boiling point generating steam which in turn strips CVOCs from the subsurface. The steam offgas produced is then extracted using SVE and, if necessary, the condensate and vapor phase are treated above ground prior to discharge. Thermal treatment would remediate areas of highest CVOC concentrations and DNAPL to concentrations amenable to further reduction by MNA. A summary of the overall protectiveness of the alternatives is provided in the table below.

Overall Protection of Human Health and the Environment

Does Not Meet Criteria	Meets Criteria
G1	G2, G4a, G4b, G3a, G3b, G3c, G5, G3b+G6/G7, G3c+G6/G7

Compliance with ARARs

Appendix A of the FS Report (CH2M HILL, 2006a) presents a compilation of all the state and federal chemical-specific, location-specific, and action-specific ARARs considered for the OMC Plant 2 site. With the exception of the No Further Action Alternative, all remedial alternatives would meet ARARs. None of the alternatives are expected to reach the PRGs during the active phase of the treatment process because of the difficulty in removing adsorbed phase CVOCs to concentrations below 1 µg/L. As a result, they rely on MNA or additional active or passive treatment to eventually reach the PRGs. The In Situ Treatment Alternatives (G3 and G5) are expected to reduce the mass of CVOCs in the aquifer much more rapidly than natural attenuation of Alternative G2 or aquifer flushing of Alternative

G4. Alternatives G6 and G7 would increase the ability of G3b or G3c to reach PRG levels and provide an additional measure of protection to downgradient receptors while the source remedies are in progress.

Air treatment for the emissions under the In Situ Thermal Treatment Alternative (G5) would be implemented if required to meet Clean Air Act and applicable IEPA-specific ARARs. The substantive requirements for obtaining injection or surface water discharge permits would be met for each alternative. A summary of the compliance with ARARs is provided in the table below.

Compliance with ARARs

Does Not Meet Criteria	Meets Criteria
G1	G2, G3a, G3b, G3c, G4a, G4b, G5, G3b+G6/G7, G3c+G6/G7

Long-Term Effectiveness and Performance

The long-term effectiveness and permanence of the In Situ Thermal Treatment Alternative (G5) and the EISB alternatives with a ZVI PRB or AS Curtain (G3b+G6/G7 and G3c+G6/G7) are the best of all alternatives because they include the active treatment of TCE, cis-1,2-dichloroethene (DCE) and vinyl chloride in groundwater, and provide additional treatment prior to offsite migration. Alternative G5 in particular ranks high because the residual heat from thermal treatment after the system is turned off stimulates biological treatment of any residual contamination. In addition, the effectiveness of Alternative G5 is less influenced by the presence of low-permeability zones.

The In Situ Chemical Reduction Alternative (G3a) is the next best alternative relative to long-term effectiveness and permanence. It has the ability to treat dissolved and adsorbed phases and high concentration areas but is limited by the lessened transport of the reducing agent to all downgradient areas. The efficiency of the Groundwater Extraction Alternatives (G4a and G4b) is directly influenced by the permeability of the aquifer and the presence of small DNAPL or high concentration areas. Pump and treat alternatives typically reach an asymptotic concentration far above PRGs as a result of dissolution from adsorbed contamination or slow diffusion out of lower permeability areas.

The long-term effectiveness of the ZVI PRBs to reduce the dissolved phase concentrations in the groundwater is related to the ability of the PRB to maintain its reactivity and hydraulic performance following installation. When designed with the appropriate safety factors, the PRB can retain sufficient performance for many years, but may have to be regenerated or replaced in the future. The effectiveness of the air sparge curtain for treating the dissolved phase is affected by the potential channeling effect of the air resulting in preferential paths and reduced removal effectiveness.

The remaining alternatives, No Further Action (G1) and MNA with Institutional Controls (G2), are similar in their long-term effectiveness and permanence, which is less than Alternatives G3a, G3b, G3c, G4a, G4b, G5, G3b+G6/G7, and G3c+G6/G7, since natural processes are the only technology relied on to reduce the concentrations of CVOCs. A summary of the relative ranking of alternatives is provided in the table below.

Long-Term Effectiveness and Performance
Relative Ranking from Lowest to Highest

Lowest **0**	**1**	**2**	**3**	**Highest** **4**
G1	G2, G4a	G4b, G3a	G3b, G3c	G5, G3b+G6/G7, G3c+G6/G7

Reduction of Toxicity, Mobility, and Volume through Treatment

Alternative G5 is the best alternative for reduction of TMV as it removes and destroys the largest mass of TCE, cis-1,2-DCE, and vinyl chloride including DNAPL. It would remove most of the estimated 12,600 pounds in the remedial target area. Alternative G5 also is anticipated to require the least amount of time to achieve a measurable reduction in TMV. Alternatives G6 and G7, when used in combination with other alternatives, can provide the necessary treatment to reduce the dissolved-phase VOC plume to PRGs before CVOC-impacted groundwater migrates offsite.

The In Situ Treatment Alternatives (G3a, G3b, G3c, G3b+G6/G7, and G3c+G6/G7) are also expected to remove a large majority of the estimated 12,600 pounds in the remedial target area. Alternative G3 plus G6 or G7 increases the effectiveness where G6 destroys contaminants and G7 removes them by mass transfer. The Groundwater Extraction Alternative G4b targets the plume exceeding MCLs, an area estimated to have 13,000 pounds of CVOCs. Alternative G4a targets the plume exceeding 1 mg/L CVOCs, or an estimated 12,600 pounds. As discussed earlier, however, a substantial amount of the CVOC mass may not be readily removable with pump and treat. Both alternatives remove the contaminants from the subsurface for treatment at an onsite treatment system prior to discharge. Alternatives G1 and G2 do not reduce the TMV of contaminants due to the lack of active treatment and do not meet the statutory preference for treatment. A summary of the relative ranking of alternatives is provided in the table below.

Reduction of Toxicity, Mobility, and Volume through Treatment
Relative Ranking from Lowest to Highest

Lowest **0**	**1**	**2**	**3**	**Highest** **4**
G1, G2	G4a	G4b	G3a, G3b, G3c, G3b+G6/G7, G3c+G6/G7	G5

Short-Term Effectiveness

There are no additional risks associated with the actual construction and implementation of the No Further Action Alternative (G1) and the MNA with Institutional Controls Alternative (G2) because no remedial construction is undertaken. These alternatives (G1 and G2), however, have short-term impacts to the community and the environment related to restrictions on possible site use and risk from existing exposure pathways. Alternative G3a has potential risks to workers related to the generation of hydrogen gas as the injected ZVI corrodes. Monitoring for explosive conditions and precautions when working around wells in the injection area will be needed to minimize risks to workers. The amounts of hydrogen potentially generated, however, are relatively small and threats to those outside the immediate area of the injection are expected to be minimal.

Alternatives G3b and G3c have minimal impacts with respect to the protection of workers during remedial construction. Alternatives G3a, G3b, and G3c have minimal impacts with respect to the protection of the community during remedial action. The addition of Alternatives G6 or G7 does not change the impact. Injections of ZVI and substrate into the aquifer both result in reducing conditions that may mobilize iron and manganese. Although the discharge and subsequent precipitation of iron and manganese are not expected to adversely impact aquatic life in the harbor, the migration of these compounds will need to be closely monitored. Alternatives G4, G5, G6, and G7 have standard safety considerations for workers due to the substantial construction required for installation (e.g., subsurface piping, installation and connection of electrical equipment, and construction of the onsite treatment systems). These are mitigated through adherence to good work practices and a focus on worker safety.

The short-term effectiveness with respect to the time until the RAOs are achieved is shortest for the In Situ Thermal Treatment Alternative (G5). The In Situ Chemical Reduction Alternative (G3a) and Enhanced In Situ Bioremediation Alternatives (G3b and G3c) will require less time than the Pump and Treat Alternatives (G4a and G4b) because they more effectively treat areas of concentrated contamination.

The No Further Action Alternative (G1) and MNA with Institutional Controls Alternative (G2) are expected to require more than 30 years to achieve the PRG levels for groundwater. A summary of the relative ranking of alternatives is provided in the table below.

Short-Term Effectiveness
Relative Ranking from Lowest to Highest

Lowest **0**	**1**	**2**	**3**	**Highest** **4**
G1,G2	G3a	G3b, G3c, G3b+G6/G7, G3c+G6/G7	G5	G4a, G4b

Implementability

All alternatives can be implemented at the site, and no technical or administrative implementability problems are expected for any of the alternatives. However, it has been assumed that the building will remain in place during implementation of all alternatives.

Cost

A summary of the estimated costs for each of the groundwater alternatives is presented on Table 5-2 and in more detail in Appendix B. The table breaks down the estimated capital, O&M, and present net worth cost.

The No Further Action Alternative has the least present worth cost, as the only task associated with this alternative is the 5-year review (assumed for 30 years).

The highest present worth cost would result from Alternative G5 at $ 37.8 million. The treatment requires extensive capital equipment, labor, and operations. The second highest present worth cost would result from implementation of Alternative G3c at $ 11.2 million. The next highest cost would be incurred from Alternative G4b at $10.6 million to implement followed by Alternative G3a at $9.6 million, and Alternative G3b at $8.3 million. Total costs associated with Alternative G3b and G3c were selected based on information obtained during the EISB pilot study. Design details, such as well spacing, were selected based on total injection volumes, anticipated labor costs, and feasibility of implementation. Alternative G2 has the lowest cost ($1.2 million) of the alternatives with the exception of the No Further Action Alternative (G1). The present worth cost of Alternative G6 and G7 are $6.2 million and $2.4 million; however, these alternatives are intended to be used in combination with Alternatives G3b or G3c.

SECTION 6

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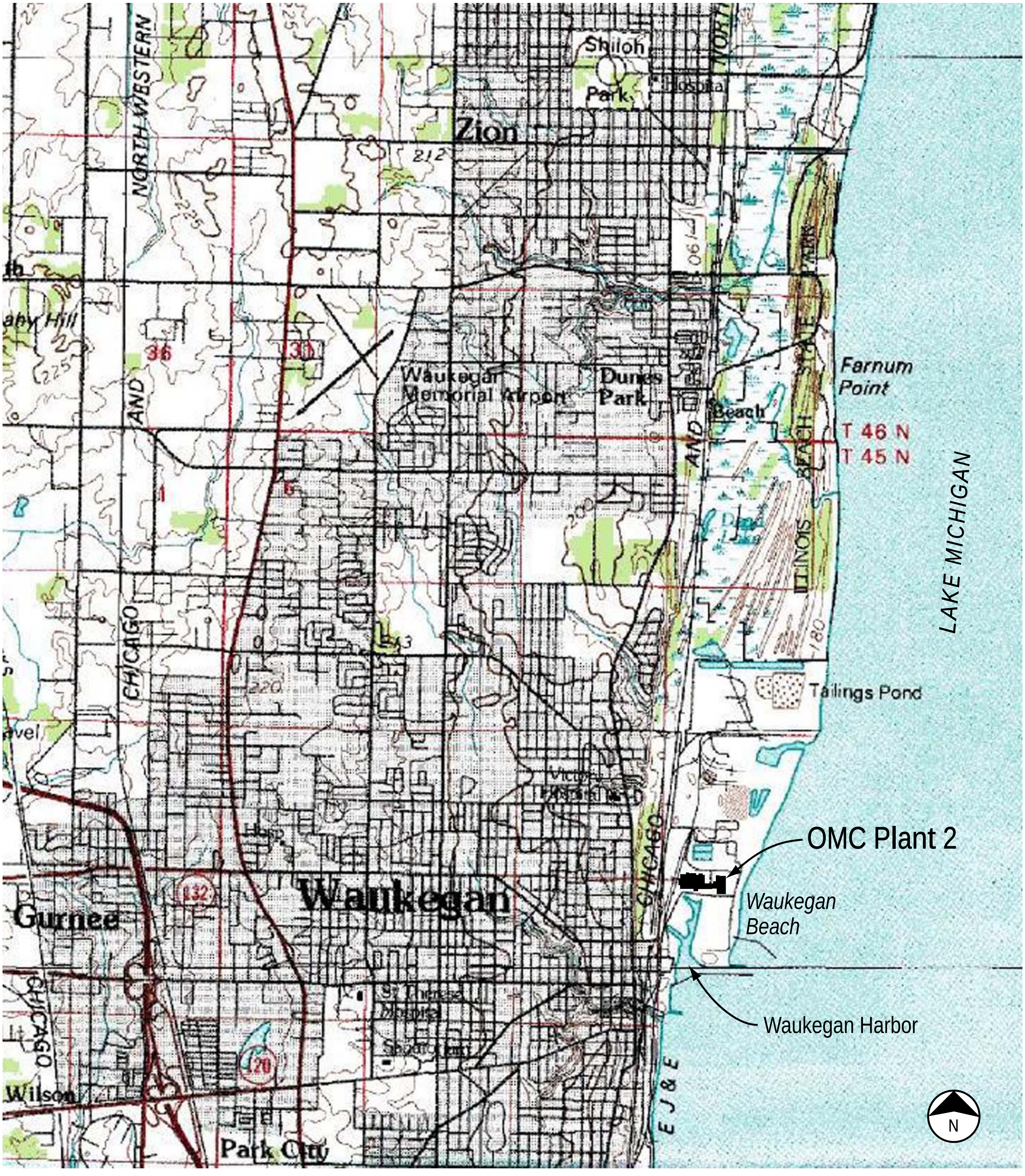
U.S. Environmental Protection Agency. 2007. *Record of Decision, Selected remedial alternatives for the OMC Plant 2 Operable Unit (OU#4) of the Outboard Marine Corporation, Inc. Superfund Site, Waukegan, Lake County, Illinois*. April.

Figures

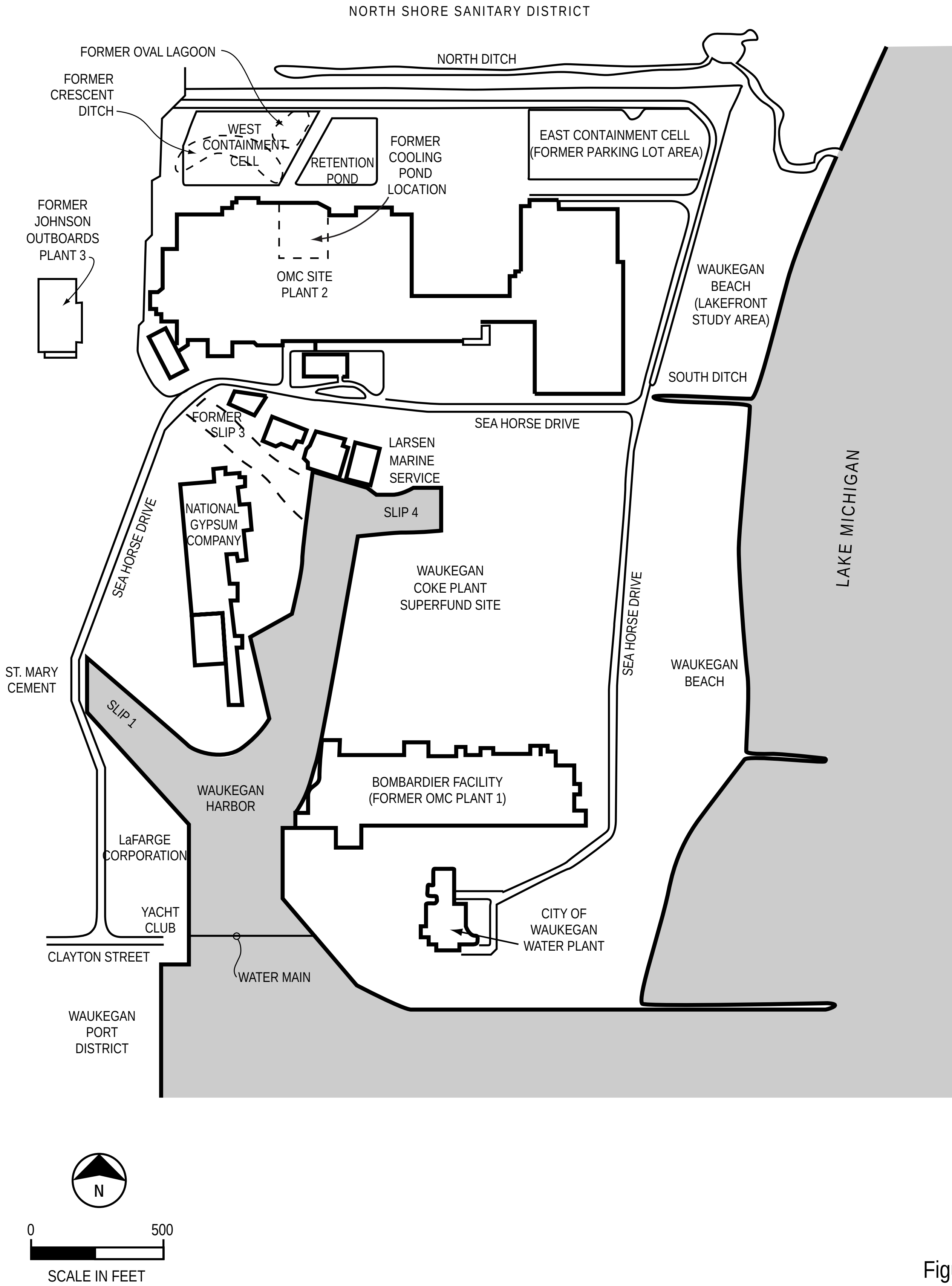


SOURCE: USGS Waukegan Quadrangle Map

0 3,000
SCALE IN FEET

Figure 1-1
Site Location Map
OMC Plant 2

CH2MHILL



SOURCE: ADAPTED FROM USEPA 2002

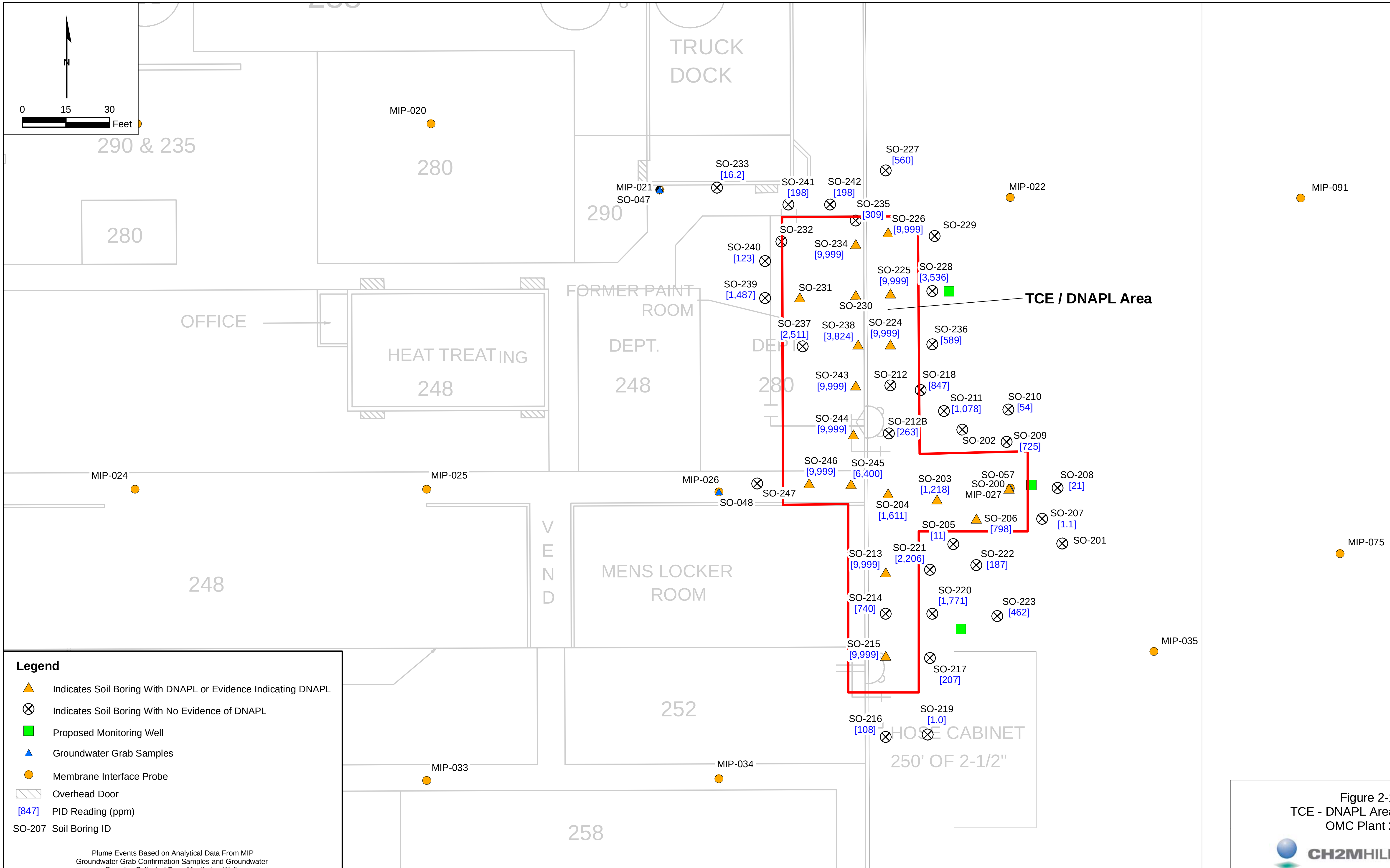
Figure 1-2
Vicinity Features
OMC Plant 2

CH2MHILL

E082005021MKE 186305.RS.01 Site Features_1-2_v2 3-29-06tll/jls

Source:
Waukegan Lakefront-Downtown Master Plan/Urban Design Plan (Skidmore, Owings & Merrill LLP, June 23, 2003)

Figure 1-3
Plan for Harborfront and North Harbor Development Districts
OMC Plant 2



Legend

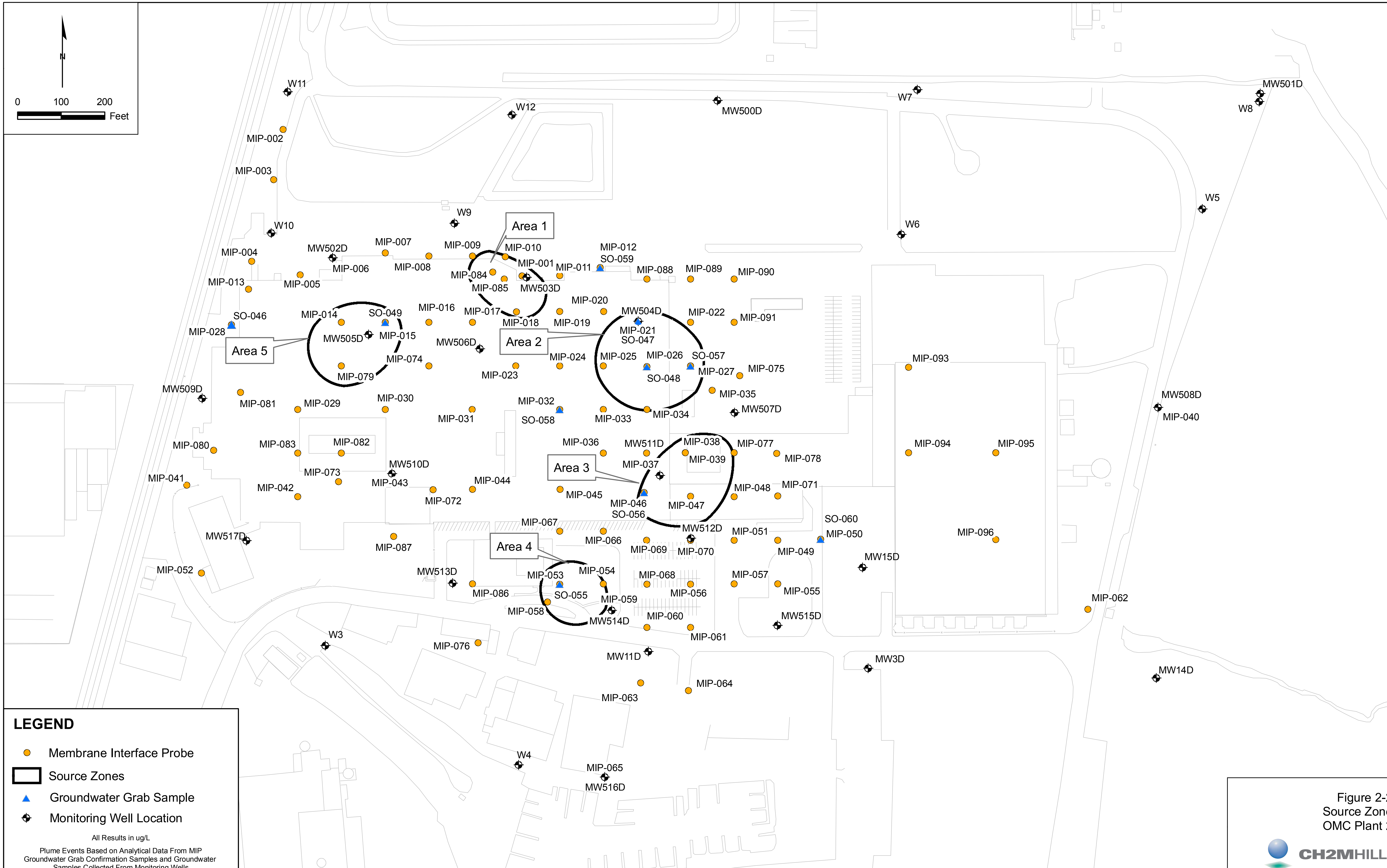
- Indicates Soil Boring With DNAPL or Evidence Indicating DNAPL
- Indicates Soil Boring With No Evidence of DNAPL
- Proposed Monitoring Well
- Groundwater Grab Samples
- Membrane Interface Probe
- Overhead Door
- [847] PID Reading (ppm)
- SO-207 Soil Boring ID

Plume Events Based on Analytical Data From MIP Groundwater Grab Confirmation Samples and Groundwater Samples Collected From Monitoring Wells

Figure 2-1
TCE - DNAPL Area
OMC Plant 2

CH2MHILL

MKE \\WAVE\PROJ\GIS\EPA\OUTBOARDMARINECORPORATION\REPORTS\2008OMC_FS_ADDENDUM\MAPFILES\FIGURE02-1_TCE_DNAPL_AREA.MXD 5/28/2008 11:09:52



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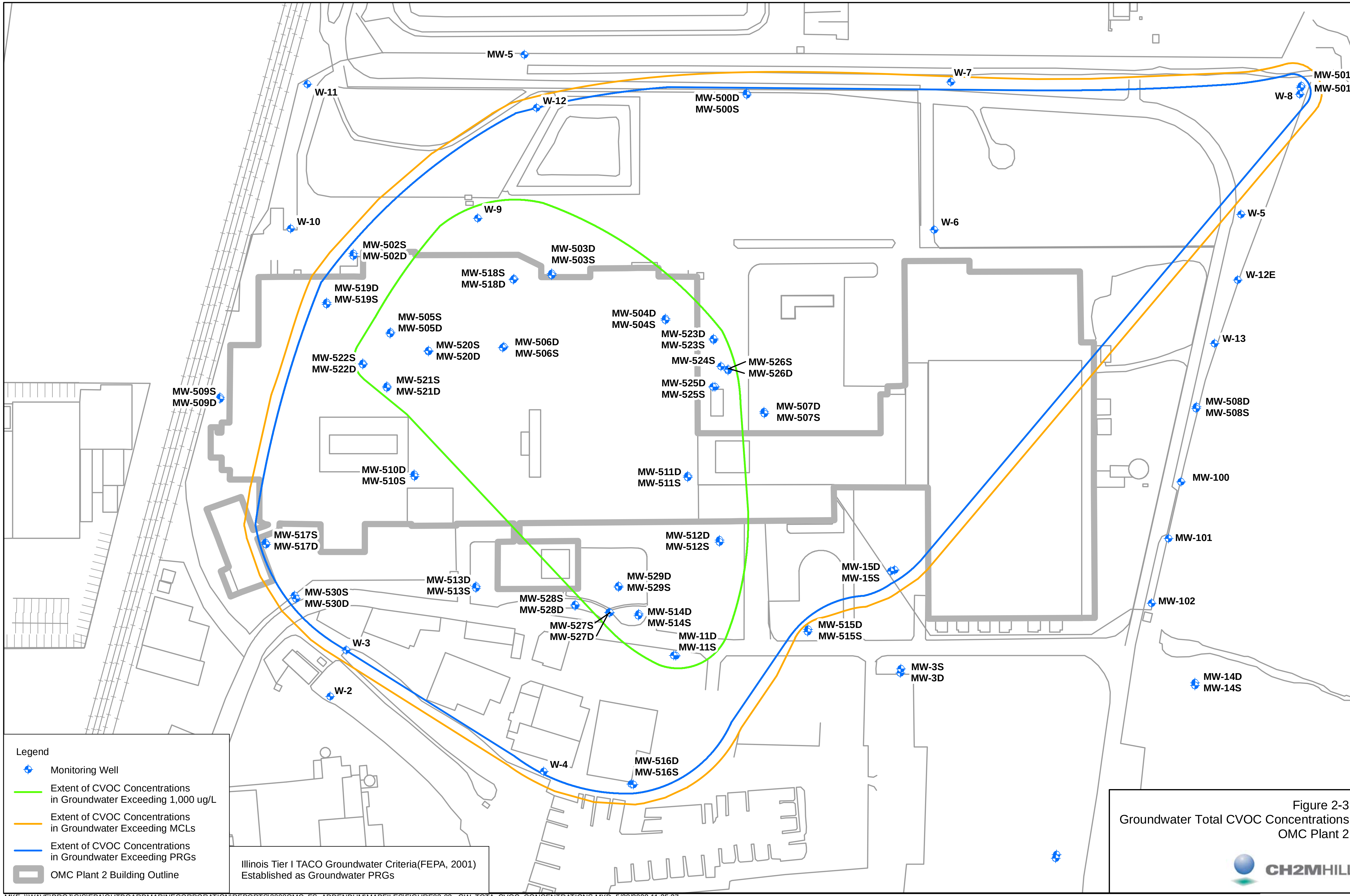
MW-5
W-11
W-12
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MW-514D
MW-514S
MW-527S
MW-527D
MW-515D
MW-515S
W-3
MW-11D
MW-11S
MW-3S
MW-3D
W-2
MW-14D
MW-14S
W-4
MW-516D
MW-516S
Legend
Monitoring Well
Extent of CVOC Concentrations in Groundwater Exceeding 1,000 ug/L
Extent of CVOC Concentrations in Groundwater Exceeding MCLs
Extent of CVOC Concentrations in Groundwater Exceeding PRGs
OMC Plant 2 Building Outline
Illinois Tier I TACO Groundwater Criteria(FEPA, 2001)
Established as Groundwater PRGs
Figure 2-3
Groundwater Total CVOC Concentrations
OMC Plant 2
CH2MHILL
MKE \\WAVE\PROJ\GIS\EPA\OUTBOARDMARINECORPORATION\REPORTS\2008OMC_FS_ADDENDUM\MAPFILES\FIGURE02-03 _GW_TOTA_CVOC_CONCENTRATIONS.MXD 5/28/2008 11:25:27

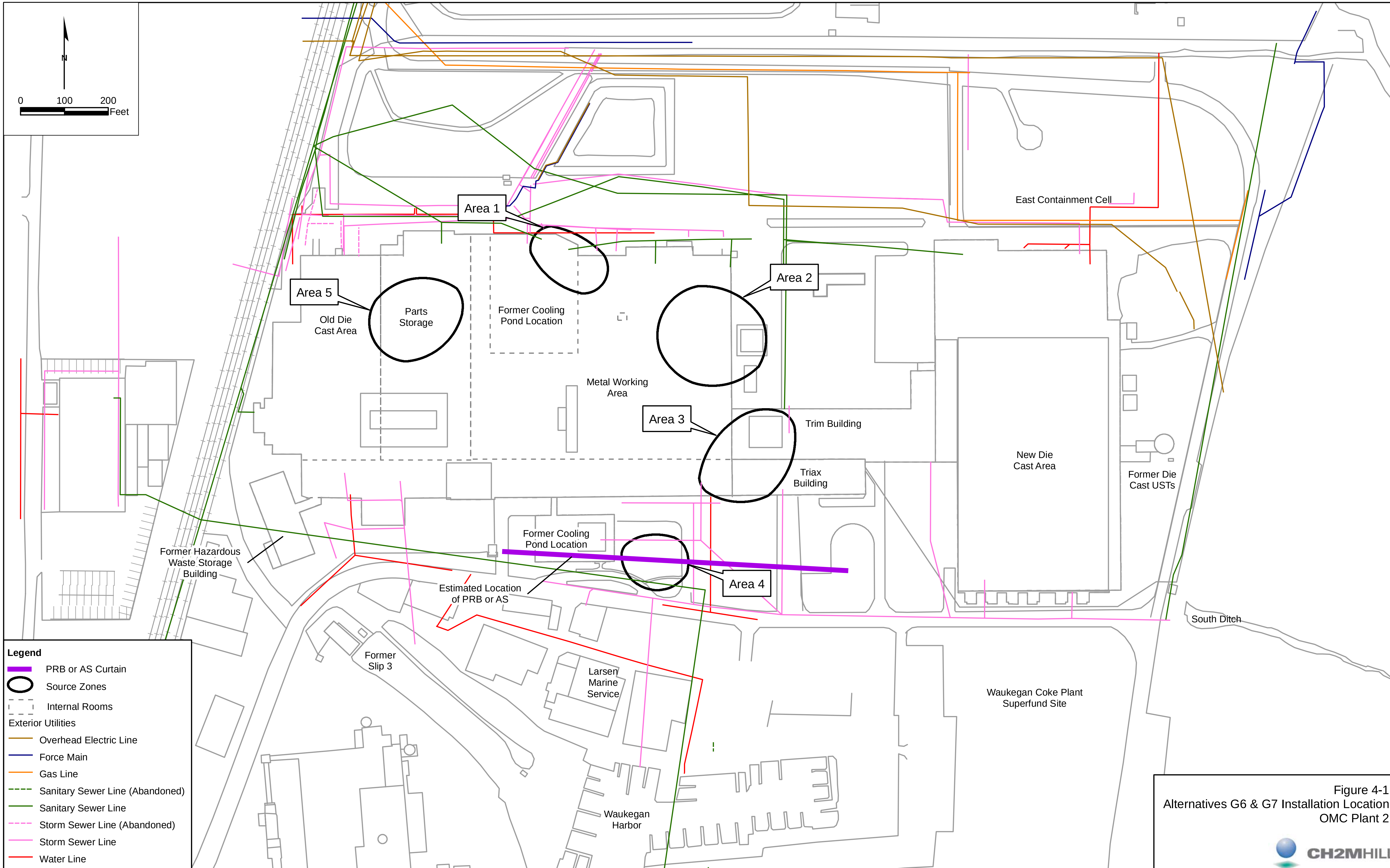

Figure 4-1
Alternatives G6 & G7 Installation Location
OMC Plant 2

CH2MHILL

MKE \\WAVE\PROJ\GIS\EPA\OUTBOARDMARINECORPORATION\REPORTS\2008OMC_FS_ADDENDUM\MAPFILES\FIGURE 04-01_ALTERNATIVES_G6_AND_G7.MXD 5/27/2008 17:01:52

Appendix A
Detailed Cost Estimates for DNAPL Alternatives

COMPARISON OF TOTAL COST OF REMEDIAL ALTERNATIVES

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report

Base Year: 2008
Date: 7/31/2008 10:07

	Alternative D1	**Alternative D2**	**Alternative D3**	**Alternative D4**	**Alternative D5**
	No Further Action	MNA and Institutional Controls	Extraction, Onsite Collection, and Offsite Destruction	In-Situ Thermal Treatment	In-Situ Soil Mixing
Total Project Duration (Years)	30	30	30	10	10
Capital Cost	$0	$150,000	$490,000	$7,190,000	$1,730,000
O&M Cost	$0	$1,640,000	$1,270,000	$2,880,000	$330,000
Periodic Cost	$90,000	$90,000	$90,000	$30,000	$30,000
Total Cost	$90,000	$1,880,000	$1,850,000	$10,100,000	$2,090,000
Total Present Value of Alternative	$30,000	$580,000	$1,160,000	$9,750,000	$1,980,000

Disclaimer: The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected during the engineering design of the remedial alternatives. This is an order-of-magnitude cost estimate that is expected to be within -50 to +100 percent of the actual project costs.

All vales rounded to $10,000

Alternative: **Alternative D1**
Name: **No Further Action**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 16:25

Description: No additional actions undertaken other than the required 5-year reviews.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
No construction				$0		
TOTAL CAPITAL COST					**$0**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
None	0	LS	$0	$0		
TOTAL ANNUAL O&M COST					**$0**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5-year Review	5	1	LS	$15,000	$15,000		
5-year Review	10	1	LS	$15,000	$15,000		
5-year Review	15	1	LS	$15,000	$15,000		
5-year Review	20	1	LS	$15,000	$15,000		
5-year Review	25	1	LS	$15,000	$15,000		
5-year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$0	$0	1.000	$0		
ANNUAL O&M COST	0 to 30	$0	$0	12.41	$0		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$90,000			$32,367		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$30,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July. (USEPA, 2000).

Alternative: **Alternative D2** — **COST ESTIMATE SUMMARY**
Name: **MNA and Institutional Controls**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:07

Description: Institutional controls include identification of DNAPL area. Confirmation groundwater sampling would be conducted annually to assure that attenuation is occuring and that the plume is not expanding.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Monitoring Well Installation					**$56,907**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	180	FT	$27	$4,860		4 shallow and 4 deep wells
2-inch PVC Well Casing (10-ft length)	140	FT	$3.19	$447		
2-inch Stainless Steel 40-slot Screen (5-ft length)	40	FT	$40	$1,600		5-ft screens
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
IDW Tranportation and Disposal	1	LS	$12,000	$12,000		Project Exper
Drilling Contractor Per Diem (2 man crew)	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus time for development
Oversight Labor	60	HR	$80	$4,800		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
SUBCONTRACT SUBTOTAL					**$71,907**	
Payment/Performance Bonds and Insurance (4%)					**$2,876**	
Contractor G&A (12.7%)					**$9,497**	
Contractor Fee (5%)					**$4,214**	
Contractor Professional/Technical Services					**$32,358**	
Project Management	10%			$7,191		USEPA 2000, p. 5-13, <$100 K
Remedial Design	20%			$14,381		USEPA 2000, p. 5-13, <$100 K
Construction Management	15%			$10,786		USEPA 2000, p. 5-13, <$100 K
Contractor Program Management					**$25,145**	
Program Management Oversight	2.5%			$3,021		
Contingency	25%			$22,124		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$145,997**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Monitoring and Soil Gas Sampling (Year 0 to 30)					**$20,160**	
Groundwater Samples from Monitoring Wells - Analytical	8	EA	$406	$3,248		
QC Samples - Analytical	2	EA	$406	$812		Assumes 15% additional samples
Water Level and DNAPL Measurement Labor	20	HRS	$85	$1,700		CH2M HILL 2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	40	HRS	$85	$3,400		CH2M HILL 2 people, 2 days, 10 hr/day
Equipment - meters, PPE	1	LS	$4,000	$4,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	30	HRS	$80	$2,400		CH2M Est.
Reporting	50	HRS	$80	$4,000		CH2M Est.
Allowance for Misc. Items	20%				**$4,032**	
Contingency	30%				**$6,048**	10% Scope + 20% Bid
Project Management	10%				**$2,016**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$504**	
SUBTOTAL ANNUAL MONITORING AND SAMPLING COST					**$32,760**	
TOTAL ANNUAL O&M COST Year 0 to 30					**$32,760**	

PERIODIC COSTS

DESCRIPTION	YEAR	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5-year review	5	1	LS	$15,000	$15,000		
5-year review	10	1	LS	$15,000	$15,000		
5-year review	15	1	LS	$15,000	$15,000		
5-year review	20	1	LS	$15,000	$15,000		
5-year review	25	1	LS	$15,000	$15,000		
5-year review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$145,997	$145,997	1.000	$145,997		
ANNUAL O&M COST	0 to 30	$1,638,000	$32,760	12.409	$406,520		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$1,873,997			$584,885		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$580,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July. (USEPA, 2000).

Alternative: **Alternative D3**
Name: **Extraction, Onsite Collection, and Offsite Destructior**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:07

Description: Mobile DNAPL would be pumped out of the subsurface using 1 extraction well and pump. DNAPL would be collected onsite for shipment to an offsite hazardous waste treatment facility.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Extraction Well Installation					**$54,640**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
8.25-inch ID Hollow-Stem Auger Drilling	60	LF	$95	$5,700		2 extraction well to 30 ft
6-inch Carbon Steel Well Riser Pipe (10-ft length)	50	LF	$37	$1,850		
6-inch Stainless Steel 40-slot Screen (5-ft length)	10	LF	$89	$890		
Well Vault and Installation	2	EA	$1,000	$2,000		CH2M HILL Est.
Surveying	1	EA	$3,000	$3,000		Project Exper
IDW Tranportation and Disposal	1	LS	$12,000	$12,000		Project Exper
Oversight Labor	30	HR	$80	$2,400		CH2M HILL 1 person
Oversight Per Diem	3	DY	$200	$600		CH2M HILL 1 person
Drilling Contractor Per Diem (2 man crew)	3	DY	$400	$1,200		
Monitoring Well Installation					**$56,907**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	180	FT	$27	$4,860		4 shallow and 4 deep wells
2-inch PVC Well Casing (10-ft length)	140	FT	$3.19	$447		
2-inch Stainless Steel 40-slot Screen (5-ft length)	40	FT	$40.00	$1,600		5-ft screens
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
IDW Tranportation and Disposal	1	LS	$12,000	$12,000		Project Exper
Drilling Contractor Per Diem (2 man crew)	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus time for development
Oversight Labor	60	HR	$80	$4,800		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
Extraction Pump & Containment System					**$89,300**	
Storage Building	1	LS	$54,000	$54,000		Assumes $60/sf and 30 x 30'
2-inch DNAPL Extraction Pump	2	EA	$7,500	$15,000		Vendor estimate including control system
Wiring	1000	FT	$2	$2,000		Vendor estimate
Discharge Tubing	1000	FT	$1	$1,000		Vendor estimate
Trenching	1000	FT	$30	$30,000		Project Exper
Level Switch	2	EA	$650	$1,300		Vendor estimate
Installation & Testing Labor	1	LS	$30,000	$30,000		
Oversight Labor	100	HR	$80	$8,000		CH2M HILL 1 person
Oversight Per Diem	10	DY	$200	$2,000		CH2M HILL 1 person
Outdoor Storage Area					**$9,000**	
Fencing Installation	1	LS	$3,500	$3,500		Project Exper
Refurbish Gas Cylinder Storage Area	1	LS	$5,000	$5,000		Project Exper
Signage	1	LS	$500	$500		Project Exper
RCRA Small Quantity Generator Permit					**$17,340**	
Characterization Sampling	1	LS	$1,500	$1,500		Two samples for analysis for VOC, PCBs, Metals, flashpoint
Sample Collection Labor	8	HR	$80	$640		CH2M HILL 1 person
Data Validation	40	HR	$80	$3,200		
Permit Application	150	HR	$80	$12,000		CH2M HILL 1 person
SUBCONTRACT SUBTOTAL					**$242,187**	
Payment/Performance Bonds and Insurance (4%)					**$9,687**	
Contractor G&A (12.7%)					**$31,988**	
Contractor Fee (5%)					**$14,193**	
Contractor Professional/Technical Services					**$108,984**	
Project Management	10%			$24,219		USEPA 2000, p. 5-13, <$100 K
Remedial Design	20%			$48,437		USEPA 2000, p. 5-13, <$100 K
Construction Management	15%			$36,328		USEPA 2000, p. 5-13, <$100 K
Contractor Program Management					**$84,690**	
Program Management Oversight	2.5%			$10,176		
Contingency	25%			$74,514		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$491,729**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Monitoring and Soil Gas Sampling (Year 0 to 30)					**$20,160**	
Groundwater Samples from Monitoring Wells - Analytical	8	EA	$406	$3,248		
QC Samples - Analytical	2	EA	$406	$812		Assumes 15% additional samples
Water Level and DNAPL Measurement Labor	20	HRS	$85	$1,700		CH2M HILL 2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	40	HRS	$85	$3,400		CH2M HILL 2 people, 2 days, 10 hr/day
Equipment - meters, PPE	1	LS	$4,000	$4,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	30	HRS	$80	$2,400		CH2M Est.
Reporting	50	HRS	$80	$4,000		CH2M Est.
Allowance for Misc. Items	20%				**$4,032**	
Contingency	30%				**$6,048**	10% Scope + 20% Bid
Project Management	10%				**$2,016**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$504**	
SUBTOTAL ANNUAL MONITORING AND SAMPLING COST					**$32,760**	
DNAPL Disposal (Year 0 to 5)					**$19,680**	
Oversight of DNAPL Loading	96	HR	$80	$7,680		CH2M HILL 1 person 8-hr visit every month
Annual DNAPL Disposal	12	DRUM	$1,000	$12,000		Assumes 55-gallons produced every month, disposal costs for haz waste
Allowance for Misc. Items	20%				**$3,936**	
Contingency	30%				**$5,904**	10% Scope + 20% Bid
Project Management	10%				**$1,968**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$492**	
SUBTOTAL ANNUAL DISPOSAL COST					**$31,980**	
System O&M (Year 0 to 5)					**$15,360**	
Pump Maintenance and DNAPL Measurement Collection	96	HR	$80	$7,680		CH2M HILL 1 person 8-hr visit per week
Building Maintenance	96	HR	$80	$7,680		CH2M HILL 1 person 8-hr visit per week
Allowance for Misc. Items	20%				**$3,072**	
Contingency	30%				**$4,608**	10% Scope + 20% Bid
Project Management	10%				**$1,536**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$384**	
SUBTOTAL ANNUAL O&M COST					**$24,960**	
TOTAL ANNUAL O&M COST Year 0 to 5					**$89,700**	
TOTAL ANNUAL O&M COST Year 6 to 30					**$32,760**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$491,729	$491,729	1.000	$491,729		
ANNUAL O&M COST	0 - 5	$448,500	$89,700	4.10	$367,788		
ANNUAL O&M COST	6 - 30	$819,000	$32,760	8.31	$272,198		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$1,849,229			$1,164,082		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$1,160,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July. (USEPA, 2000).

Alternative: **Alternative D4**
Name: **In-Situ Thermal Treatment**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:07

Description: Treatment of DNAPL using thermal wells and heated extraction wells and soil-vapor extraction wells to extract volatilized contaminants. Treatment of extracted contaminants with vapor & liquid treatment system.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
ISTD System Installation					**$1,391,150**	
Mobilization and Site Prep	1	LS	$285,000	$285,000		Includes submittals
Drilling Mobilization	1	LS	$5,000	$5,000		CH2M HILL Est.
6.25-inch ID Hollow-Stem Auger Drilling	750	FT	$64	$47,700		Assumes 25 wells x 30 feet deep/well
4-inch Carbon Steel Well Riser Pipe (10-ft length)	125	FT	$18	$2,250		
4-inch Stainless Steel 40-slot Screen (5-ft length)	625	FT	$45	$28,125		Assumes 25 feet/well
Well Vaults	25	EA	$1,000	$25,000		CH2M HILL Est.
Well Development	25	EA	$400	$10,000		IPS Drilling Quote
Drilling Contractor Per Diem (2 man crew)	14	DY	$400	$5,600		1 crew per day, 3 locations per day plus time for well development
Oversight Labor	140	HR	$80	$11,200		CH2M HILL 1 person, 10 hrs/day
Oversight Per Diem	14	DY	$200	$2,800		CH2M HILL 1 person, 3 locations per day plus development
IDW Tranportation and Disposal	1	LS	$20,000	$20,000		Project Exper
Well Decommissioning	25	EA	$500	$12,500		Contractor Estimate
Demobilization	1	LS	$75,000	$75,000		Contractor Estimate
Electrical Installation	1	LS	$345,000	$345,000		Assumes installation of transformers and high voltage line.
Electrical Connection	1	LS	$350,000	$350,000		CH2M HILL Estimate
Well Field Piping	2,500	FT	$6.39	$15,975		CH2M HILL Estimate
Shakedown Testing	1	LS	$150,000	$150,000		Contractor Estimate
Monitoring Well Installation					**$59,907**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	180	FT	$27	$4,860		4 shallow and 4 deep wells
2-inch PVC Well Casing (10-ft length)	140	FT	$3.19	$447		
2-inch Stainless Steel 40-slot Screen (5-ft length)	40	FT	$40	$1,600		5-ft screens
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
IDW Tranportation and Disposal	1	LS	$12,000	$12,000		Project Exper
Drilling Contractor Per Diem (2 man crew)	5	DY	$1,000	$5,000		1 crew per day, 1 deep and 2 shallow locations per day plus time for developr
Oversight Labor	60	HR	$80	$4,800		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
Groundwater Treatment System					**$2,146,577**	
Remediation Building w/ Electrical and HVAC	1	LS	$195,000	$195,000		Assumes $60/square foot and 65 feet x 50 feet
5,000 Gallon Tank	1	EA	$7,954	$7,954		RS Means 33-10- 9660
MCC	1	EA	$40,000	$40,000		CH2M HILL Est.
GAC Treatment System	1	EA	$110,000	$110,000		Contractor Quotation
I&C (transducers, etc)	25	EA	$20,000	$500,000		CH2M HILL Est.
Transfer Pump	4	EA	$6,500	$26,000		CH2M HILL Est.
PLC w/ Autodialer	1	LS	$35,000	$35,000		CH2M HILL Est.
Fittings, Valves, Miscellaneous Appertanances	1	LS	$20,000	$20,000		CH2M HILL Est.
Discharge Flowmeter	1	EA	$12,000	$12,000		CH2M HILL Est.
Discharge Pipe	1,000	EA	$6.39	$6,390		Supplier Quotation
Heat Tracing	4,580	FT	$10	$45,800		CH2M HILL Est.
Bag Filters	4	EA	$250	$1,000		CH2M HILL Est.
Rotating Vacuum Drum Filter	1	EA	$100,000	$100,000		Supplier Quotation
pH Adjustment Storage Tanks	2	EA	$7,954	$15,908		RS Means 33-10-9660
Mixer	3	EA	$4,362	$13,087		RS Means 33-13-0428
Mixing Tank	3	EA	$4,714	$14,141		RS Means 33-10-9658
Chemical Feeder	3	EA	$3,099	$9,297		RS Means 33-12-9905
DAF System	1	EA	$123,000	$123,000		Supplier Quotation
Polymer Feed System	1	EA	$23,000	$23,000		Supplier Quotation
Dosing Pump	2	EA	$5,000	$10,000		Supplier Quotation
Air Compressor	1	EA	$5,000	$5,000		Supplier Quotation
System Programming	200	HRS	$100	$20,000		CH2M HILL Est.
Startup - Labor	200	HRS	$80	$16,000		CH2M HILL 2 persons
Startup - Equipment	1	LS	$3,000	$3,000		CH2M Est.
Startup - Consumables	1	LS	$5,000	$5,000		CH2M Est.
Mechanical Installation	1	LS	$330,000	$330,000		CH2M HILL Est.
Electrical Installation	1	LS	$460,000	$460,000		CH2M HILL Est.
Offgas Treatment System					**$480,000**	
Thermal Oxidizer	1	LS	$200,000	$200,000		
VOC Scruber	1	LS	$100,000	$100,000		
Mechanical Installation	1	LS	$75,000	$75,000		CH2M HILL Est.
Electrical Installation	1	LS	$105,000	$105,000		CH2M HILL Est.
SUBCONTRACT SUBTOTAL					**$4,077,634**	
Payment/Performance Bonds and Insurance (4%)					**$163,105**	
Contractor G&A (12.7%)					**$538,574**	
Contractor Fee (5%)					**$238,966**	
Contractor Professional/Technical Services					**$774,750**	
Project Management	5%			$203,882		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$326,211		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$244,658		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$1,399,395**	
Program Management Oversight	2.5%			$144,826		
Contingency	25%			$1,254,570		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$7,192,424**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Monitoring and Soil Gas Sampling (Year 0 to 10)					**$20,160**	
Groundwater Samples from Monitoring Wells	8	EA	$406	$3,248		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples	2	EA	$406	$812		15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		CH2M HILL 2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	40	HRS	$85	$3,400		CH2M HILL 2 people, 2 days, 10 hr/day
Equipment - meters, PPE	1	LS	$4,000	$4,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	30	HRS	$80	$2,400		CH2M Est.
Reporting	50	HRS	$80	$4,000		CH2M Est.
Allowance for Misc. Items	20%				**$4,032**	
Contingency	30%				**$6,048**	10% Scope + 20% Bid
Project Management	10%				**$2,016**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$504**	
SUBTOTAL ANNUAL MONITORING AND SAMPLING COST					**$32,760**	
Treatment System Operation and Maintenance (Year 0 to 2)					**$811,687**	
Routine Operations, Maintenance, Monitoring	2080	HR	$80	$166,400		Assumes 5 days/week
Waste Transport	11	EA	$115	$1,256		Assumes 20 tons/load non-hazardous
Waste Disposal	218	TON	$18	$3,931		Assumes non-hazardous
pH Adjustment - Acid	18,250	GAL	$1	$18,250		Assumes 98% sulfuric acid
pH Adjustment - Base	23,725	GAL	$2	$47,450		Assumes 20% NaOH
Monthly Influent/Effluent Sampling Analytical	12	EA	$60	$720		VOC analysis inlcuding QC
Data Validation, Database Management	96	HR	$80	$7,680		
DNAPL Disposal	18000	GAL	$7	$126,000		Assumes 75 percent of DNAPL is removed; haz disposal
Electricity	12	MO	$15,000	$180,000		
Electricity for ISTD System Operation	3,000,000	kWH	$0.08	$240,000		
Reporting	1	LS	$20,000	$20,000		
Groundwater Discharge	63,072,000	GAL	$0.00	$0		Assumes NPDES Discharge at 2 GPM/EW
Allowance for Misc. Repair Items	15%				**$121,753**	
Contingency	30%				**$243,506**	10% Scope + 20% Bid
Project Management	10%				**$81,169**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$20,292**	
SUBTOTAL ANNUAL O&M COST					**$1,278,407**	
TOTAL ANNUAL O&M COST Year 0 to 2					**$1,311,167**	
TOTAL ANNUAL O&M COST Year 3 to 10					**$32,760**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$30,000**	
5-year review	5	1	LS	$15,000	$15,000		
5-year review	10	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$30,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$7,192,424	$7,192,424	1.000	$7,192,424		
ANNUAL O&M COST	0 to 2	$2,622,334	$1,311,167	1.81	$2,370,614		
ANNUAL O&M COST	3 to 10	$262,080	$32,760	5.22	$170,862		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
		$10,106,838			$9,752,220		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$9,750,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July. (USEPA, 2000).

Alternative: **Alternative D5**
Name: **In-Situ Soil Mixing**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: DNAPL
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:07

Description: Soils would be mixed with bentonite clay and zero-valent iron using large diameter augers to stabilize and treat DNAPL area approximately 7,200 square feet with a DNAPL thickness of 2 feet.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Soil Mixing					**$838,740**	
Mobilization/Demobilization	1	LS	$250,000	$250,000		Includes submittals;
Soil Mixing	8000	CY	$45	$360,000		Geo-Solutions Quotation
ZVI Amendment	168	TN	$680	$114,240		Assumed 1.4 ton/cy of soil, 25% moisture, and 2% iron
Clay Amendment	84	TN	$250	$21,000		Vendor quote for 3000 lb/bags delivered
Installation of Potable Water Line	1	LS	$50,000	$50,000		CH2M HILL Est.
Access Restriction (Fencing)	1	LS	$3,500	$3,500		CH2M HILL Est.
Oversight Labor	400	HR	$80	$32,000		CH2M HILL 2 person, 10 hr/day
Oversight Per Diem	20	DY	$400	$8,000		CH2M HILL 2 person, assumes 400 cy/day
Soil Confirmation Sampling					**$25,500**	
Soil Confirmation Samples During Mixing	20	EA	$150	$3,000		CH2M HILL Est.
Soil Confirmation Samples Post-Mixing	20	EA	$150	$3,000		Project. Experience
Direct Push Contractor	5	DY	$2,500	$12,500		Contractor estimated daily rate
Contractor Per Diem	5	DY	$400	$2,000		IPS Drilling Quotation
Oversight Labor	50	HRS	$80	$4,000		CH2M HILL 1 Person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 Person
Monitoring Well Installation					**$64,907**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	180	FT	$27	$4,860		4 shallow and 4 deep wells
2-inch PVC Well Casing (10-ft length)	140	FT	$3.19	$447		
2-inch Stainless Steel 40-slot Screen (5-ft length)	40	FT	$40.00	$1,600		5-ft screens
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
IDW Tranportation and Disposal	1	LS	$20,000	$20,000		Project Exper
Drilling Contractor Per Diem (2 man crew)	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus time fo
Oversight Labor	60	HR	$80	$4,800		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
SUBCONTRACT SUBTOTAL					**$944,147**	
Payment/Performance Bonds and Insurance (4%)					**$37,766**	
Contractor G&A (12.7%)					**$124,703**	
Contractor Fee (5%)					**$55,331**	
Contractor Professional/Technical Services					**$245,478**	
Project Management	6%			$56,649		USEPA 2000, p. 5-13, $500-$2M
Remedial Design	12%			$113,298		USEPA 2000, p. 5-13, $500-$2M
Construction Management	8%			$75,532		USEPA 2000, p. 5-13, $500-$2M
Contractor Program Management					**$325,672**	
Program Management Oversight	2.5%			$35,186		
Contingency	25%			$290,487		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$1,733,096**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Monitoring and Soil Gas Sampling (Year 0 to 10)					**$20,100**	
Groundwater Samples from Monitoring Wells - Analytical	8	EA	$400	$3,200		
QC Samples - Analytical	2	EA	$400	$800		Assumes 15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		CH2M HILL 2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	40	HRS	$85	$3,400		CH2M HILL 2 people, 2 days, 10 hr/day
Equipment - meters, PPE	1	LS	$4,000	$4,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	30	HRS	$80	$2,400		CH2M Est.
Reporting	50	HRS	$80	$4,000		CH2M Est.
Allowance for Misc. Items	20%				**$4,020**	
Contingency	30%				**$6,030**	10% Scope + 20% Bid
Project Management	10%				**$2,010**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$503**	
SUBTOTAL ANNUAL MONITORING AND SAMPLING COST					**$32,663**	
TOTAL ANNUAL O&M COST Year 0 to 10					**$32,663**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$30,000**	
5-year review	5	1	LS	$15,000	$15,000		
5-year review	10	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$30,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$1,733,096	$1,733,096	1.000	$1,733,096		
ANNUAL O&M COST	1 to 10	$326,625	$32,663	7.02	$229,408		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
		$2,089,721			$1,980,824		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$1,980,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July. (USEPA, 2000).

Appendix B

Detailed Cost Estimates for Groundwater Alternatives

COMPARISON OF TOTAL COST OF REMEDIAL ALTERNATIVES

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report

Base Year: 2008
Date: 7/31/2008 16:23

	Alternative G1	Alternative G2	Alternative G3a	Alternative G3b	Alternative G3c	Alternative G4a	Alternative G4b	Alternative G5	Alternative G6	Alternative G7
	No Further Action.	MNA and Institutional Controls.	In-Situ Chemical Reduction	Enhanced In-Situ Bioremediation with a Soluble Substrate	Enhanced In-Situ Bioremediation with a Food Grade Oil	Groundwater Collection and Treatment with Monitored Natural Attenuation	Groundwater Collection and Treatment to MCLs	In-Situ Thermal Treatment	Permeable Reactive Barrier	Air Sparge Curtain
Total Project Duration (Years)	30	30	30	30	30	30	30	10	30	30
Capital Cost	$0	$130,000	$8,300,000	$3,640,000	$5,410,000	$3,720,000	$4,450,000	$15,480,000	$6,080,000	$790,000
O&M Cost	$0	$2,170,000	$2,890,000	$6,740,000	$8,150,000	$6,930,000	$12,030,000	$24,870,000	$340,000	$3,980,000
Periodic Cost	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$90,000	$30,000	$0	$0
Total Cost	$90,000	$2,390,000	$11,280,000	$10,470,000	$13,650,000	$10,740,000	$16,570,000	$40,380,000	$6,420,000	$4,770,000
Total Present Value of Alternative	$30,000	$1,060,000	$9,610,000	$8,300,000	$11,240,000	$8,040,000	$10,600,000	$37,840,000	$6,220,000	$2,430,000

Disclaimer: The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected during the engineering design of the remedial alternatives. This is an order-of-magnitude cost estimate that is expected to be within -50 to +100 percent of the actual project costs.

All vales rounded to $10,000

Alternative: **Alternative G1**
Name: **No Further Action.**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: No additional actions undertaken other than the required 5 year reviews.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
No construction				$0		
TOTAL CAPITAL COST					**$0**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
None	0	LS	$0	$0		
TOTAL ANNUAL O&M COST					**$0**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$0	$0	1.000	$0		
ANNUAL O&M COST	1 to 30	$0	$0	12.41	$0		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$90,000			$32,367		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$30,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G2**
Name: **MNA and Institutional Controls.**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: Confirmation groundwater sampling would be conducted annually to assure that attenuation is occuring and that the plume is not expanding.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Additional Monitoring Well Installation					**$51,248**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	360	FT	$27	$9,720		8 shallow and 8 deep wells
2-inch PVC Well Casing (10-ft length)	280	FT	$4	$1,176		
2-inch PVC Well 40-slot Screen (5-ft length)	80	FT	$7.50	$600		
2-inch Expanding Locking Cap	16	EA	$22	$352		
Monitoring Well Completion - Flush	16	EA	$250	$4,000		IPS Drilling Quote
Monitoring Well Development	16	EA	$400	$6,400		Project Exper
Drilling Contractor Per Diem (2 man crew)	10	DY	$400	$4,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 wells/day for development
Oversight Labor	100	HR	$80	$8,000		CH2M HILL 1 person
Oversight Per Diem	10	DY	$200	$2,000		CH2M HILL 1 person
SUBCONTRACT SUBTOTAL					**$66,248**	
Payment/Performance Bonds and Insurance (4%)					**$2,650**	
Contractor G&A (12.7%)					**$8,750**	
Contractor Fee (5%)					**$3,882**	
Contractor Professional/Technical Services					**$29,812**	
Project Management	10%			$6,625		USEPA 2000, p. 5-13, <$100 K
Remedial Design	20%			$13,250		USEPA 2000, p. 5-13, <$100 K
Construction Management	15%			$9,937		USEPA 2000, p. 5-13, <$100 K
Contractor Program Management					**$23,166**	
Program Management Oversight	2.5%			$2,784		
Contingency	25%			$20,383		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$134,508**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Groundwater Monitoring Natural Attentuation Sampling					**$44,488**	
Groundwater Samples from Monitoring Wells - Analytical	20	EA	$406	$8,120		
QC Samples - Analytical	3	EA	$406	$1,218		Assumes 15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$72,293**	
TOTAL ANNUAL O&M COST Year 0 to 30					**$72,293**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$134,508	$134,508	1.000	$134,508		
ANNUAL O&M COST	0 to 30	$2,168,790	$72,293	12.409	$897,087		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$2,393,298			$1,063,962		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$1,060,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G3a** **COST ESTIMATE SUMMARY**
Name: **In-Situ Chemical Reduction**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: ISCR includes injection of chemical amendments into the groundwater to treat the groundwater plume of CVOC concentrations greater than 1 mg/L to concentrations amenable to MNA.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Injection of ISCR Amendment					**$4,555,500**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
ISCR Amendment	2,137,500	LB	$2	$3,847,500		Vendor Quotation, assumes 0.25 amendment to soil mass ratio
ISCR Amendment Injection	180	DY	$2,450	$441,000		Vendor Quotation
Injection Subcontractor Per Diem	180	DY	$400	$72,000		Project Exper
Oversight Labor	1800	HR	$80	$144,000		CH2M HILL 1 person, 10 hr/day
Oversight Per Diem	180	DY	$200	$36,000		
Monitoring Well Installation					**$51,248**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
4.25-inch ID Hollow-Stem Auger Drilling	360	FT	$27	$9,720		8 shallow and 8 deep wells
2-inch PVC Well Casing (10-ft length)	280	FT	$4	$1,176		
2-inch PVC Well 40-slot Screen (5-ft length)	80	FT	$8	$600		
2-inch Expanding Locking Cap	16	EA	$22	$352		
Monitoring Well Completion - Flush	16	EA	$250	$4,000		
Monitoring Well Development	16	EA	$400	$6,400		
Drilling Contractor Per Diem (2 man crew)	10	DY	$400	$4,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 wells/day for development
Oversight Labor	100	HR	$80	$8,000		CH2M HILL 1 person
Oversight Per Diem	10	DY	$200	$2,000		CH2M HILL 1 person
Mixing and Support Equipment					**$82,316**	
Installation of Potable Water Line	1	LS	$50,000	$50,000		CH2M HILL Est.
5,000 Gallon Above-Ground Tank	1	EA	$7,954	$7,954		Unit Costs Derived from Means Unit Prices
Product mixer	1	EA	$4,362	$4,362		Unit Costs Derived from Means Unit Prices
Installation of Electrical Service	1	LS	$20,000	$20,000		
SUBCONTRACT SUBTOTAL					**$4,704,064**	
Payment/Performance Bonds and Insurance (4%)					**$188,163**	
Contractor G&A (12.7%)					**$621,313**	
Contractor Fee (5%)					**$275,677**	
Contractor Professional/Technical Services					**$893,772**	
Project Management	5%			$235,203		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$376,325		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$282,244		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$1,614,379**	
Program Management Oversight	2.5%			$167,075		
Contingency	25%			$1,447,304		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$8,297,368**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Groundwater Monitoring Sampling Event					**$44,488**	
Groundwater Samples from Monitoring Wells - Analytical	20	EA	$406	$8,120		
QC Samples - Analytical	3	EA	$406	$1,218		Assumes 15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL GROUNDWATER SAMPLING EVENT COST					**$72,293**	
TOTAL ANNUAL O&M COST Year 0 to 3					**$289,172**	Quarterly sampling for 3 years
TOTAL ANNUAL O&M COST Year 4 to 30					**$72,293**	Annual sampling

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$8,297,368	$8,297,368	1.000	$8,297,368		
ANNUAL O&M COST	0 to 3	$867,516	$289,172	2.624	$758,879		
ANNUAL O&M COST	4 to 30	$2,024,204	$72,293	9.78	$517,647		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$11,279,088			$9,606,261		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$9,610,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G3b** **COST ESTIMATE SUMMARY**
Name: **Enhanced In-Situ Bioremediation with a Soluble Substrate**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: EISB includes injection of biological amendments into the groundwater to treat the groundwater plume of CVOC concentrations greater than 1 mg/L to concentrations amenable to MNA.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Injection Well Installation					**$903,043**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals; 3 Crews; Contractor Quote
Hollow-Stem Auger Drilling (4.25" ID)	8,220	FT	$27	$221,940		Shallow well to 15-ft and deep to 30-ft
2-inch PVC Well Casing	6,325	FT	$4	$26,565		Contractor Quote
2-inch Stainless Steel Well Screen (5ft)	1,895	FT	$40	$75,800		Contractor Quote
2-inch Locking Well Plugs	379	EA	$22	$8,338		Century Products, Inc.
Injection Well Completion - Flush	379	EA	$250	$94,750		Contractor Quote
Injection Well Development	379	EA	$400	$151,600		Contractor Quote
Drilling Crew Per Diem	74	DY	$1,200	$88,300		3 crews per day, 3 deep and 6 shallow locations per day plus 12 wells/day for development
Oversight Labor	2,208	HR	$80	$176,600		CH2M HILL 3 people; 10 hours/day
Oversight Per Diem	74	DY	$600	$44,150		CH2M HILL 3 people
Additional Monitoring Well Installation					**$33,124**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
Hollow-Stem Auger Drilling (4.25" ID)	180	FT	$27	$4,860		4 shallow and 4 deep wells/area
2-inch PVC Well Casing	140	FT	$4	$588		Indelco
2-inch PVC Well Screen	40	FT	$8	$300		Century Products, Inc.
2-inch Locking Well Plugs	8	EA	$22	$176		Century Products, Inc.
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
Drilling Crew Per Diem	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 wells/day for development
Oversight Labor	50	HR	$80	$4,000		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
Investigation Derived Waste Handling					**$146,907**	
Frac Tank Rental	6	MO	$6,000	$33,717		Assumes five 18,000 gal frac tanks (includes drop-off and return fees)
Development Water Disposal	77,400	GAL	$1.21	$93,886		Assumes 200 gallons per well, non-hazardous disposal
Carbon for Water Treatment	4	LS	$500	$1,935		Assume 1-55-gal drum treats 20,000 gallons of water
Rolloff Box Rental	6	MO	$2,000	$11,239		Assume 4 rolloffs with 15 tons per rolloff (includes drop-off and return fees)
Soil Cuttings Transportation and Disposal	49	TONS	$125	$6,130		Assume that 0.0036 cy of soil per linear ft of 4.25" borehole; 1.6 tons/cy
Initial Annual EISB Injections (4 injections/year)					**$963,465**	
Mob/Demob Injection Equipment	4	EVENT	$2,500	$10,000		
EISB Material - Annual	111,298	LB	$1.20	$133,557		CH2M HILL Est.
Equipment Rental	160	DY	$2,230	$356,800		40 days/injection, 4 injections
Injection Crew Labor	4	EVENT	$64,000	$256,000		CH2M HILL 2 People; 40 days/injection; 10 hrs/day
Injection Crew Per Diem	160	DY	$400	$64,000		CH2M HILL 2 People; 4 Injections; 40 days/injection
Subcontractor 2 man crew per diem	160	DY	$400	$64,000		
Water Cost - Annual	2,602,344	GAL	$0.0035	$9,108		Based on 2008 Waukegan, IL water costs
Installation of Potable Water Line	1	LS	$50,000	$50,000		CH2M HILL Est.
Installation of Electrical Service	1	LS	$20,000	$20,000		Project Exper
SUBCONTRACT SUBTOTAL					**$2,061,539**	
Payment/Performance Bonds and Insurance (4%)					**$82,462**	
Contractor G&A (12.7%)					**$272,288**	
Contractor Fee (5%)					**$120,814**	
Contractor Professional/Technical Services					**$391,692**	
Project Management	5%			$103,077		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$164,923		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$123,692		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$707,496**	
Program Management Oversight	2.5%			$73,220		
Contingency	25%			$634,276		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$3,636,291**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	YEAR	QTY	UNIT	COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Sampling						**$44,488**	
Groundwater Samples from Monitoring Wells - Analytical		20	EA	$406	$8,120		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples - Analytical		3	EA	$406	$1,218		15% additional samples
Water Level Measurement Labor		20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor		250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters		1	LS	$2,000	$2,000		CH2M Est.
Consumables		1	LS	$600	$600		CH2M Est.
Data Validation		40	HRS	$80	$3,200		CH2M Est.
Reporting		80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items		20%				**$8,898**	
Contingency		30%				**$13,346**	10% Scope + 20% Bid
Project Management		10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight		2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST						**$72,293**	
Annual EISB Injections (4 injections/year for Year 1 to 3)						**$893,465**	
Mob/Demob Injection Equipment		4	EVENT	$2,500	$10,000		
EISB Material - Annual		111,298	LB	$1.20	$133,557		CH2M HILL Est.
Equipment Rental		160	DY	$2,230	$356,800		40 days/injection, 4 injections
Injection Crew Labor		4	EACH	$64,000	$256,000		CH2M HILL 2 People; 40 days/injection; 10 hrs/day
Injection Crew Per Diem		160	DY	$400	$64,000		CH2M HILL 2 People; 4 Injections; 40 days/injection
Subcontractor 2 man crew per diem		160	DY	$400	$64,000		
Water Cost - Annual		2,602,344	GAL	$0.0035	$9,108		Based on 2008 Waukegan, IL water costs
Allowance for Misc. Items		20%				**$178,693**	
Contingency		30%				**$268,040**	10% Scope + 20% Bid
Project Management		10%				**$89,347**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight		2.5%				**$22,337**	
SUBTOTAL ANNUAL INJECTION COST						**$1,451,881**	
TOTAL ANNUAL O&M COST Year 0						**$72,293**	
TOTAL ANNUAL O&M COST Year 1 to 3						**$1,524,174**	
TOTAL ANNUAL O&M COST Year 4 to 30						**$72,293**	

PERIODIC COSTS

DESCRIPTION	YEAR	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$3,636,291	$3,636,291	1	$3,636,291		
ANNUAL O&M COST - Sampling	0 to 30	$2,168,790	$72,293	12.409	$897,087		
ANNUAL O&M COST - Injection	1 to 3	$4,572,523	$1,524,174	2.453	$3,738,238		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$10,467,604			$8,303,984		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$8,300,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G3c** — **COST ESTIMATE SUMMARY**

Name: **Enhanced In-Situ Bioremediation with a Food Grade Oil**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: EISB includes injection of biological amendments into the groundwater to treat the groundwater plume of CVOC concentrations greater than 1 mg/L to concentrations amenable to MNA.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Injection Well Installation					**$983,153**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals; 3 Crews; Contractor Quote
Hollow-Stem Auger Drilling (4.25" ID)	6,210	FT	$27	$167,670		Shallow well to 15-ft and deep to 30-ft
2-inch PVC Well Casing	6,325	FT	$40	$253,000		Contractor Quote
2-inch Stainless Steel Well Screen (5ft)	1,895	FT	$85	$161,075		Contractor Quote
2-inch Locking Well Plugs	289	EA	$22	$6,358		Century Products, Inc.
Injection Well Completion - Flush	289	EA	$250	$72,250		Contractor Quote
Injection Well Development	289	EA	$250	$72,250		Contractor Quote
Drilling Crew Per Diem	56	DY	$1,200	$67,300		3 crews per day, 3 deep and 6 shallow locations per day plus 12 wells/day for development
Oversight Labor	1,683	HR	$80	$134,600		CH2M HILL 3 people; 10 hours/day
Oversight Per Diem	56	DY	$600	$33,650		CH2M HILL 3 people
Additional Monitoring Well Installation					**$33,124**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
Hollow-Stem Auger Drilling (4.25" ID)	180	FT	$27	$4,860		4 shallow and 4 deep wells/area
2-inch PVC Well Casing	140	FT	$4	$588		Century Products, Inc.
2-inch PVC Well Screen	40	FT	$8	$300		Century Products, Inc.
2-inch Locking Well Plugs	8	EA	$22	$176		Century Products, Inc.
Monitoring Well Completion - Flush	8	EA	$250	$2,000		Century Products, Inc.
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
Drilling Crew Per Diem	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 wells/day for development
Oversight Labor	50	HR	$80	$4,000		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
Investigation Derived Waste Handling					**$118,489**	
Frac Tank Rental	5	MO	$6,000	$30,217		Assumes five 18,000 gal frac tanks (includes drop-off and return fees)
Development Water Disposal	59,400	GAL	$1.21	$72,052		Assumes 200 gallons per well, non-hazardous disposal
Carbon for Water Treatment	3	LS	$500	$1,485		Assume 1-55-gal drum treats 20,000 gallons of water
Rolloff Box Rental	5	MO	$2,000	$10,072		Assume 4 rolloffs with 15 tons per rolloff (includes drop-off and return fees)
Soil Cuttings Transportation and Disposal	37	TONS	$125	$4,663		Assume that 0.0036 cy of soil per linear ft of 4.25" borehole; 1.6 tons/cy
Initial Annual EISB Injections (1 injection/2 year)					**$1,931,791**	
Mob/Demob Injection Equipment	1	EVENT	$2,500	$2,500		
EISB Material	656,451	LB	$2.50	$1,641,128		CH2M HILL Est.
Equipment Rental	47	DY	$2,230	$104,810		47 days/injection, 1 injection
Injection Crew Labor	1	EVENT	$75,200	$75,200		CH2M HILL 2 People; 47 days/injection; 10 hrs/day
Injection Crew Per Diem	47	DY	$400	$18,800		CH2M HILL 2 People; 47 days/injection
Subcontractor 2 man crew per diem	47	DY	$400	$18,800		
Water Cost	158,032	GAL	$0.0035	$553		Based on 2008 Waukegan, IL water costs
Installation of Potable Water Line	1	LS	$50,000	$50,000		CH2M HILL Est.
Installation of Electrical Service	1	LS	$20,000	$20,000		Project Exper
SUBCONTRACT SUBTOTAL					**$3,066,557**	
Payment/Performance Bonds and Insurance (4%)					**$122,662**	
Contractor G&A (12.7%)					**$405,031**	
Contractor Fee (5%)					**$179,713**	
Contractor Professional/Technical Services					**$582,646**	
Project Management	5%			$153,328		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$245,325		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$183,993		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$1,052,406**	
Program Management Oversight	2.5%			$108,915		
Contingency	25%			$943,491		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$5,409,015**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Sampling (Year 0 to 30)					**$44,488**	
Groundwater Samples from Monitoring Wells	20	EA	$406	$8,120		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples	3	EA	$406	$1,218		15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$72,293**	
Annual EISB Injections (1 injection/2 year for Year 2 and 4)					**$1,861,791**	
Mob/Demob Injection Equipment	1	EVENT	$2,500	$2,500		
EISB Material	656,451	LB	$2.50	$1,641,128		CH2M HILL Est.
Equipment Rental	47	DY	$2,230	$104,810		47 days/injection
Injection Crew Labor	1	EACH	$75,200	$75,200		CH2M HILL 2 People; 47 days/injection; 10 hrs/day
Injection Crew Per Diem	47	DY	$400	$18,800		CH2M HILL 2 People; 47 days/injection
Subcontractor 2 man crew per diem	47	DY	$400	$18,800		
Water Cost	158,032	GAL	$0.0035	$553		Based on 2008 Waukegan, IL water costs
Allowance for Misc. Items	20%				**$372,358**	
Contingency	30%				**$558,537**	10% Scope + 20% Bid
Project Management	10%				**$186,179**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$46,545**	
SUBTOTAL ANNUAL INJECTION COST					**$3,025,411**	
TOTAL ANNUAL O&M COST Year 0, 2, 4					**$3,097,704**	
TOTAL ANNUAL O&M COST Year 1, 3, 5 to 30					**$72,293**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$5,409,015	$5,409,015	1	$5,409,015		
ANNUAL O&M COST - Sampling	1	$72,293	$72,293	0.93	$67,564		
ANNUAL O&M COST - Sampling and Injection	2	$3,097,704	$3,097,704	0.87	$2,705,654		
ANNUAL O&M COST - Sampling	3	$72,293	$72,293	0.82	$59,013		
ANNUAL O&M COST - Sampling and Injection	4	$3,097,704	$3,097,704	0.76	$2,363,223		
ANNUAL O&M COST - Sampling	5 to 30	$1,807,325	$72,293	8.309	$600,671		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$13,646,333			$11,237,507		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$11,240,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G4a** — **COST ESTIMATE SUMMARY**

Name: **Groundwater Collection and Treatment with Monitored Natural Attenuation**

Site:	OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL	**Description:**	Institutional controls include Classification Exception Area.
Media:	Groundwater		Groundwater collection with 30 - 4-inch diameter EWs
Phase:	Supplemental Feasibility Study Report		and treatment using an activated carbon process with discharge of treated effluent
Base Year:	2008		to Lake Michigan via NPDES. Treatment continuing until groundwater concentrations
Date:	7/31/2008 10:37		are amenable to MNA, approximately 10 years.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Extraction Well Installation					**$475,039**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
6.25-inch ID Hollow-Stem Auger Drilling	900	FT	$64	$57,240		30 well at 30-feet deep
4-inch Carbon Steel Well Riser Pipe (10-ft length)	450	FT	$18	$8,100		
4-inch Stainless Steel 40-slot Screen (5-ft length)	450	FT	$45	$20,250		Assumes 15-ft screen/extraction well
36" Well Vault	30	EA	$1,000	$30,000		CH2M HILL Est.
Well Development	30	EA	$400	$12,000		IPS Drilling Quote
1-inch HDPE Conveyance Piping	2000	FT	$0.28	$560		Contractor Quotation
2-inch HDPE Conveyance Piping	500	FT	$0.83	$415		Contractor Quotation
4-inch HDPE Conveyance Piping	1880	FT	$2.95	$5,546		Contractor Quotation
6-inch HDPE Conveyance Piping	200	FT	$6.39	$1,278		Contractor Quotation
Miscellaneous pipe fittings	1	LS	$25,000	$25,000		Contractor Quotation
Trenching	4580	LF	$30	$137,400		Project Exper
Groundwater Extraction Pumps	30	EA	$4,500	$135,000		Contractor Quotation
Oversight Labor	172.5	HR	$80	$13,800		CH2M HILL 1 person, 10 hrs/day
Oversight Per Diem	17	DY	$200	$3,450		CH2M HILL 1 person, 2 extraction well per day plus development
Groundwater Treatment System					**$1,620,577**	
Remediation Building w/ Electrical & HVAC	1	LS	$195,000	$195,000		Assumes $60/sf and 65' x 50'
5,000 Gallon Tank	1	EA	$7,954	$7,954		RS Means 33-10- 9660
MCC	1	EA	$60,000	$60,000		CH2M HILL Est.
GAC Treatment System	1	EA	$60,000	$60,000		Includes delivery and installation
I&C (transducers, etc)	1	LS	$100,000	$100,000		CH2M HILL Est.
Transfer Pump	4	EA	$6,500	$26,000		CH2M HILL Est.
PLC w/ Autodialer	1	LS	$35,000	$35,000		CH2M HILL Est.
Fittings, Valves, Miscellaneous Appertanances	1	LS	$20,000	$20,000		CH2M HILL Est.
Discharge Flowmeter	1	EA	$12,000	$12,000		CH2M HILL Est.
Discharge Pipe	1000	FT	$6.39	$6,390		Supplier Quotation, assumes 6-inch HDPE discharge to north ditch
Heat Tracing	4580	FT	$10	$45,800		CH2M HILL Est.
Bag Filters	4	EA	$1,000	$4,000		CH2M HILL Est.
Rotating Vacuum Drum Filter	1	EA	$200,000	$200,000		Supplier Quotation
pH Adjustment Storage Tanks	2	EA	$7,954	$15,908		RS Means 33-10-9660
Mixer	3	EA	$4,362	$13,087		RS Means 33-13-0428
Mixing Tank	3	EA	$4,714	$14,141		RS Means 33-10-9658
Chemical Feeder	3	EA	$3,099	$9,297		RS Means 33-12-9905
DAF System	1	EA	$123,000	$123,000		Supplier Quotation
Polymer Feed System	1	EA	$23,000	$23,000		Supplier Quotation
Dosing Pump	2	EA	$5,000	$10,000		Supplier Quotation
Air Compressor	1	EA	$5,000	$5,000		Supplier Quotation
System Programming	200	HRS	$100	$20,000		CH2M HILL Est.
Startup - Labor	200	HRS	$80	$16,000		CH2M Est. - 2 persons for 2 weeks
Startup - Equipment	1	LS	$3,000	$3,000		CH2M Est.
Startup - Consumables	1	LS	$5,000	$5,000		CH2M Est.
Mechanical Installation	1	LS	$246,000	$246,000		CH2M HILL Est.
Electrical Installation	1	LS	$345,000	$345,000		CH2M HILL Est.
SUBCONTRACT SUBTOTAL					**$2,110,616**	
Payment/Performance Bonds and Insurance (4%)					**$84,425**	
Contractor G&A (12.7%)					**$278,770**	
Contractor Fee (5%)					**$123,691**	
Contractor Professional/Technical Services					**$401,017**	
Project Management	5%			$105,531		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$168,849		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$126,637		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$724,338**	
Program Management Oversight	2.5%			$74,963		
Contingency	25%			$649,375		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$3,722,857**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Sampling (Year 1 to 30)					**$44,488**	
Groundwater Samples from Monitoring Wells	20	EA	$406	$8,120		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples	3	EA	$406	$1,218		15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$66,732**	
Treatment System Operation and Maintenance					**$312,907**	
Routine Operations, Maintenance, Monitoring	1,040	HR	$80	$83,200		Assumes 2 days/week
Waste Transport	11	EA	$300	$3,276		Assumes 20 tons/load non-hazardous
Waste Disposal	218	TON	$18	$3,931		Assumes non-hazardous
pH Adjustment - Acid	18,250	GAL	$1	$18,250		Assumes 98% sulfuric acid
pH Adjustment - Base	23,725	GAL	$2	$47,450		Assumes 20% NaOH
Monthly Influent/Effluent Sampling Labor	96	HR	$80	$7,680		1 Site Visit Per Month
Monthly Influent/Effluent Sampling Analytical	12	EA	$120	$1,440		VOC analysis inlcuding QC
Data Validation, Database Management	96	HR	$80	$7,680		
Electricity	12	MO	$10,000	$120,000		
Reporting	1	LS	$20,000	$20,000		
Groundwater Discharge	31,536,000	GAL	$0.00	$0		Assumes NPDES Discharge at 2 GPM/EW
Allowance for Misc. Repair Items	15%				**$46,936**	
Contingency	30%				**$93,872**	10% Scope + 20% Bid
Project Management	10%				**$31,291**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$7,823**	
SUBTOTAL ANNUAL O&M COST					**$492,829**	
TOTAL ANNUAL O&M COST Year 1 to 10					**$559,561**	
TOTAL ANNUAL O&M COST Year 11 to 30					**$66,732**	

PERIODIC COSTS

DESCRIPTION	YEAR	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$3,722,857	$3,722,857	1.000	$3,722,857		
ANNUAL O&M COST	1 to 10	$5,595,608	$559,561	7.02	$3,930,121		
ANNUAL O&M COST	11 to 30	$1,334,640	$66,732	5.39	$359,382		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$10,743,105			$8,044,728		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$8,040,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000)

Alternative: **Alternative G4b** **COST ESTIMATE SUMMARY**
Name: **Groundwater Collection and Treatment to MCLs**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: Institutional controls include Classification Exception Area. Groundwater collection with 60 - 4-inch diameter EWs and treatment using an activated carbon process with discharge of treated effluent to Lake Michigan via NPDES. Treatment continuing until groundwater concentrations meet MCLs, approximately 20 years.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
Extraction Well Installation					**$808,519**	
Mobilization/Demobilization	1	LS	$25,000	$25,000		Includes submittals
6.25-inch ID Hollow-Stem Auger Drilling	1,800	FT	$64	$114,480		60 extraction wells at 30-feet deep
4-inch Carbon Steel Well Riser Pipe (10-ft length)	900	FT	$18	$16,200		
4-inch Stainless Steel 40-slot Screen (5-ft length)	900	FT	$45	$40,500		Assumes 15-ft screen/extraction well
36" Well Vault	60	EA	$1,000	$60,000		CH2M HILL Est.
Well Development	60	EA	$400	$24,000		IPS Drilling Quote
1-inch HDPE Conveyance Piping	2,500	FT	$0.28	$700		Contractor Quotation
2-inch HDPE Conveyance Piping	500	FT	$0.83	$415		Contractor Quotation
4-inch HDPE Conveyance Piping	1,880	FT	$2.95	$5,546		Contractor Quotation
6-inch HDPE Conveyance Piping	200	FT	$6.39	$1,278		Contractor Quotation
Miscellaneous pipe fittings	1	LS	$44,000	$44,000		Contractor Quotation
Trenching	4580	LF	$30	$137,400		Project Exper
Groundwater Extraction Pumps	60	EA	$4,500	$270,000		Contractor Quotation
Oversight Labor	690	HR	$80	$55,200		CH2M HILL 1 person, 10 hrs/day
Oversight Per Diem	69	DY	$200	$13,800		CH2M HILL 1 person, 2 extraction well per day plus development
Groundwater Treatment System					**$1,700,577**	
Remediation Building w/ Electrical & HVAC	1	LS	$195,000	$195,000		Assumes $60/sf and 65' x 50'
5,000 Gallon Tank	1	EA	$7,954	$7,954		RS Means 33-10- 9660
MCC	1	EA	$60,000	$60,000		CH2M HILL Est.
GAC Treatment System	1	EA	$110,000	$110,000		Includes delivery and installation
I&C (transducers, etc)	1	LS	$100,000	$100,000		CH2M HILL Est.
Transfer Pump	4	EA	$6,500	$26,000		CH2M HILL Est.
PLC w/ Autodialer	1	LS	$35,000	$35,000		CH2M HILL Est.
Fittings, Valves, Miscellaneous Appertanances	1	LS	$20,000	$20,000		CH2M HILL Est.
Discharge Flowmeter	1	EA	$12,000	$12,000		CH2M HILL Est.
Discharge Pipe	1000	FT	$6.39	$6,390		Supplier Quotation, assumes 6-inch HDPE discharge to north ditch
Heat Tracing	4580	FT	$10	$45,800		CH2M HILL Est.
Bag Filters	4	EA	$1,000	$4,000		CH2M HILL Est.
Rotating Vacuum Drum Filter	1	EA	$200,000	$200,000		Supplier Quotation
pH Adjustment Storage Tanks	2	EA	$7,954	$15,908		RS Means 33-10-9660
Mixer	3	EA	$4,362	$13,087		RS Means 33-13-0428
Mixing Tank	3	EA	$4,714	$14,141		RS Means 33-10-9658
Chemical Feeder	3	EA	$3,099	$9,297		RS Means 33-12-9905
DAF System	1	EA	$123,000	$123,000		Supplier Quotation
Polymer Feed System	1	EA	$23,000	$23,000		Supplier Quotation
Dosing Pump	2	EA	$5,000	$10,000		Supplier Quotation
Air Compressor	1	EA	$5,000	$5,000		Supplier Quotation
System Programming	200	HRS	$100	$20,000		CH2M HILL Est.
Startup - Labor	200	HRS	$80	$16,000		CH2M Est. - 2 persons for 2 weeks
Startup - Equipment	1	LS	$3,000	$3,000		CH2M Est.
Startup - Consumables	1	LS	$5,000	$5,000		CH2M Est.
Mechanical Installation	1	LS	$259,000	$259,000		CH2M HILL Est.
Electrical Installation	1	LS	$362,000	$362,000		CH2M HILL Est.
SUBCONTRACT SUBTOTAL					**$2,524,096**	
Payment/Performance Bonds and Insurance (4%)					**$100,964**	
Contractor G&A (12.7%)					**$333,383**	
Contractor Fee (5%)					**$147,922**	
Contractor Professional/Technical Services					**$479,578**	
Project Management	5%			$126,205		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$201,928		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$151,446		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$866,240**	
Program Management Oversight	2.5%			$89,649		
Contingency	25%			$776,591		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$4,452,183**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Sampling (Year 1 to 30)					**$44,488**	
Groundwater Samples from Monitoring Wells	20	EA	$406	$8,120		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples	3	EA	$406	$1,218		15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$72,293**	
Treatment System Operation and Maintenance					**$312,907**	
Routine Operations, Maintenance, Monitoring	1040	HR	$80	$83,200		Assumes 2 days/week
Waste Transport	11	EA	$300	$3,276		Assumes 20 tons/load non-hazardous
Waste Disposal	218	TON	$18	$3,931		Assumes non-hazardous
pH Adjustment - Acid	18,250	GAL	$1	$18,250		Assumes 98% sulfuric acid
pH Adjustment - Base	23,725	GAL	$2	$47,450		Assumes 20% NaOH
Monthly Influent/Effluent Sampling Labor	96	HR	$80	$7,680		1 Site Visit Per Month
Monthly Influent/Effluent Sampling Analytical	12	EA	$120	$1,440		VOC analysis inlcuding QC
Data Validation, Database Management	96	HR	$80	$7,680		
Electricity	12	MO	$10,000	$120,000		
Reporting	1	LS	$20,000	$20,000		
Groundwater Discharge	63,072,000	GAL	$0.00	$0		Assumes NPDES Discharge at 2 GPM/EW
Allowance for Misc. Repair Items	15%				**$46,936**	
Contingency	30%				**$93,872**	10% Scope + 20% Bid
Project Management	10%				**$31,291**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$7,823**	
SUBTOTAL ANNUAL O&M COST					**$492,829**	
TOTAL ANNUAL O&M COST Year 1 to 20					**$565,122**	
TOTAL ANNUAL O&M COST Year 21 to 30					**$72,293**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$90,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
5 year Review	15	1	LS	$15,000	$15,000		
5 year Review	20	1	LS	$15,000	$15,000		
5 year Review	25	1	LS	$15,000	$15,000		
5 year Review	30	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$90,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$4,452,183	$4,452,183	1.000	$4,452,183		
ANNUAL O&M COST	1 to 20	$11,302,437	$565,122	10.59	$5,986,909		
ANNUAL O&M COST	21 to 30	$722,930	$72,293	1.82	$131,214		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
PERIODIC COST	15	$15,000	$15,000	0.36	$5,437		
PERIODIC COST	20	$15,000	$15,000	0.26	$3,876		
PERIODIC COST	25	$15,000	$15,000	0.18	$2,764		
PERIODIC COST	30	$15,000	$15,000	0.13	$1,971		
		$16,567,549			$10,602,672		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$10,600,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G5** — **COST ESTIMATE SUMMARY**
Name: **In-Situ Thermal Treatment**

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Media: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: Treatment of groundwater using thermal wells and heated extraction wells and soil-vapor extraction wells to extract volatilized contaminants. Treatment of extracted contaminants with vapor & liquid treatment system.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Institutional Controls (Groundwater Use Restrictions)	1	LS	$15,000	$15,000	**$15,000**	
ISTD System Installation					**$6,598,391**	
Mobilization & Site Prep	1	LS	$285,000	$285,000		Includes submittals
Drilling Mobilization	3	LS	$5,000	$15,000		CH2M HILL Est.
Hollow-Stem Auger Drilling (6.25" ID)	29,250	FT	$64	$1,860,300		Assumes 975 wells x 30 Feet Deep/Well
4-inch Carbon Steel Well Casing	4,875	FT	$18	$87,750		Assumes 5 Feet/Well
4-inch Stainless Steel Well Screen	24,375	FT	$45	$1,096,875		
Well Vaults	975	EA	$1,000	$975,000		CH2M HILL Est.
Well Development	975	EA	$400	$390,000		IPS Drilling Quote
Drilling Contractor Per Diem (2 man crew)	325	DY	$400	$130,000		1 crew per day, 3 locations per day plus time for well development
Oversight Labor	3250	HR	$80	$260,000		CH2M HILL 1 person, 10 hrs/day
Oversight Per Diem	325	DY	$200	$65,000		CH2M HILL 1 person, 2 extraction well per day plus development
Well Decommissioning	975	EA	$500	$487,500		Contractor Estimate
Demobilization	1	LS	$75,000	$75,000		Contractor Estimate
Electrical Installation	1	LS	$341,700	$341,700		CH2M HILL Estimate
Electrical Connection	1	LS	$350,000	$350,000		CH2M HILL Estimate
Well Field Piping	4,580	FT	$6.39	$29,266		CH2M HILL Estimate
Shakedown Testing	1	LS	$150,000	$150,000		Contractor Estimate
Groundwater Treatment System					**$1,700,577**	
Remediation Building w/ Electrical & HVAC	1	LS	$195,000	$195,000		Assumes $60/sf and 65' x 50'
5,000 Gallon Tank	1	EA	$7,954	$7,954		RS Means 33-10- 9660
MCC	1	EA	$60,000	$60,000		CH2M HILL Est.
GAC Treatment System	1	EA	$110,000	$110,000		Contractor Quotation
I&C (transducers, etc)	1	LS	$100,000	$100,000		CH2M HILL Est.
Transfer Pump	4	EA	$6,500	$26,000		CH2M HILL Est.
PLC w/ Autodialer	1	LS	$35,000	$35,000		CH2M HILL Est.
Fittings, Valves, Miscellaneous Appertanances	1	LS	$20,000	$20,000		CH2M HILL Est.
Discharge Flowmeter	1	EA	$12,000	$12,000		CH2M HILL Est.
Discharge Pipe	1,000	EA	$6.39	$6,390		Supplier Quotation
Heat Tracing	4,580	EA	$10	$45,800		CH2M HILL Est.
Bag Filters	4	EA	$1,000	$4,000		CH2M HILL Est.
Rotating Vacuum Drum Filter	1	EA	$200,000	$200,000		Supplier Quotation
pH Adjustment Storage Tanks	2	EA	$7,954	$15,908		RS Means 33-10-9660
Mixer	3	EA	$4,362	$13,087		RS Means 33-13-0428
Mixing Tank	3	EA	$4,714	$14,141		RS Means 33-10-9658
Chemical Feeder	3	EA	$3,099	$9,297		RS Means 33-12-9905
DAF System	1	EA	$123,000	$123,000		Supplier Quotation
Polymer Feed System	1	EA	$23,000	$23,000		Supplier Quotation
Dosing Pump	2	EA	$5,000	$10,000		Supplier Quotation
Air Compressor	1	EA	$5,000	$5,000		Supplier Quotation
System Programming	200	HRS	$100	$20,000		CH2M HILL Est.
Startup - Labor	200	HRS	$80	$16,000		CH2M Est. - 2 persons
Startup - Equipment	1	LS	$3,000	$3,000		CH2M Est.
Startup - Consumables	1	LS	$5,000	$5,000		CH2M Est.
Mechanical Installation	1	LS	$259,000	$259,000		CH2M HILL Est.
Electrical Installation	1	LS	$362,000	$362,000		CH2M HILL Est.
Offgas Treatment System					**$480,000**	
Thermal Oxidizer	1	LS	$200,000	$200,000		
VOC Scruber	1	LS	$100,000	$100,000		
Mechanical Installation	25	PERCENT	$300,000	$75,000		CH2M HILL Est.
Electrical Installation	35	PERCENT	$300,000	$105,000		CH2M HILL Est.
SUBCONTRACT SUBTOTAL					**$8,778,968**	
Payment/Performance Bonds and Insurance (4%)					**$351,159**	
Contractor G&A (12.7%)					**$1,159,526**	
Contractor Fee (5%)					**$514,483**	
Contractor Professional/Technical Services					**$1,668,004**	
Project Management	5%			$438,948		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$702,317		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$526,738		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$3,012,837**	
Program Management Oversight	2.5%			$311,803		
Contingency	25%			$2,701,034		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$15,484,977**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual Groundwater Sampling					**$44,488**	
Groundwater Samples from Monitoring Wells	20	EA	$406	$8,120		Annual sampling of monitoring wells for VOCs, Metals and MNA parameters
QC Samples	3	EA	$406	$1,218		15% additional samples
Water Level Measurement Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Groundwater Sampling Labor	250	HRS	$85	$21,250		5 people, 5 days, 10 hr/day
Equipment - meters	1	LS	$2,000	$2,000		CH2M Est.
Consumables	1	LS	$600	$600		CH2M Est.
Data Validation	40	HRS	$80	$3,200		CH2M Est.
Reporting	80	HRS	$80	$6,400		CH2M Est.
Allowance for Misc. Items	20%				**$8,898**	
Contingency	30%				**$13,346**	10% Scope + 20% Bid
Project Management	10%				**$4,449**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,112**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$72,293**	
Treatment System Operation and Maintenance					**$7,666,207**	
Routine Operations, Maintenance, Monitoring	1040	HR	$80	$83,200		Assumes 2 days/week
Waste Transport	11	EA	$300	$3,276		Assumes 20 tons/load non-hazardous
Waste Disposal	218	TON	$18	$3,931		Assumes non-hazardous
pH Adjustment - Acid	29,250	GAL	$1	$29,250		Assumes 98% sulfuric acid
pH Adjustment - Base	4,875	GAL	$2	$9,750		Assumes 20% NaOH
Monthly Influent/Effluent Sampling Labor	96	HR	$80	$7,680		1 Site Visit Per Month
Monthly Influent/Effluent Sampling Analytical	12	EA	$120	$1,440		VOC analysis inlcuding QC
Data Validation, Database Management	96	HR	$80	$7,680		
Electricity	12	MO	$25,000	$300,000		
Electricity for ISTD System Operation	90,000,000	kWH	$0.08	$7,200,000		
Reporting	1	LS	$20,000	$20,000		
Groundwater Discharge	63,072,000	GAL	$0.00	$0		Assumes NPDES Discharge at 2 GPM/EW
Allowance for Misc. Repair Items	15%				**$1,149,931**	
Contingency	30%				**$2,299,862**	10% Scope + 20% Bid
Project Management	10%				**$766,621**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$191,655**	
SUBTOTAL ANNUAL O&M COST					**$12,074,276**	
TOTAL ANNUAL O&M COST Year 1 to 2					**$12,146,569**	
TOTAL ANNUAL O&M COST Year 2 to 10					**$72,293**	

PERIODIC COSTS

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$30,000**	
5 year Review	5	1	LS	$15,000	$15,000		
5 year Review	10	1	LS	$15,000	$15,000		
TOTAL PERIODIC COST						**$30,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$15,484,977	$15,484,977	1.000	$15,484,977		
ANNUAL O&M COST (system operation)	1 to 2	$24,293,139	$12,146,569	1.81	$21,961,218		
ANNUAL O&M COST (MNA only)	3 to10	$578,344	$72,293	5.22	$377,049		
PERIODIC COST	5	$15,000	$15,000	0.71	$10,695		
PERIODIC COST	10	$15,000	$15,000	0.51	$7,625		
		$40,386,460			$37,841,564		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$37,840,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G6**

Name: **Permeable Reactive Barrier**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Location: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: 800 foot long ZVI PRB; Reactive zone 5 to 30 feet bgs + 2 feet into Till
Shallow zone influent = 2200 ppb VC; effluent 0.2 ppb VC; GW velocity = 70-150 ft/yr
Deep zone influent = 13000 ppb VC; effluent 0.2 ppb VC; GW velocity = 6-30 ft/yr
Four additional groundwater monitoring wells in addition to existing network to monitor effectiveness

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Pre-Construction Activities					**$ 38,325**	
Bench testing	1	LS	$27,375	$27,375		ETI Estimate
Survey	1	LS	$10,950	$10,950		CH2M HILL Est.
Construction Activities					**$ 147,825**	
Pre-Construction Submittals	1	LS	$10,950	$10,950		CH2M HILL Est.
Site Preparation	1	LS	$27,375	$27,375		CH2M HILL Est.
Utility location, relocation, and restoration	1	LS	$109,500	$109,500		Utility corridor in vicinity of proposed PRB; CH2M HILL Est.
PRB Installation					**$3,230,437**	
Construction of PRB; includes media preparation	25,600	SF	$27	$700,800		Bioslurry construction method
ZVI	2,010	TONS	$849	$1,705,736		ETI Quote based on design conditions
Sand	1,407	CY	$44	$61,644		
Placement of soil backfill	444	CY	$44	$19,467		
Offsite Transportation, and Disposal of Non-Haz Wastes	3,564	TONS	$82	$290,502		Subtitle D, Non-hazardous; Onyx, includes characterization
Site Restoration	1	LS	$27,375	$27,375		CH2M HILL Est.
Post Construction Submittals	1	LS	$8,213	$8,213		
License Fee	15%			$416,700		Percentage of Construction Costs Only
Additional Monitoring Well Installation					**$33,124**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
Hollow-Stem Auger Drilling (4.25" ID)	180	FT	$27	$4,860		4 shallow and 4 deep wells/area
2-inch PVC Well Casing	140	FT	$4	$588		IPS Drilling Quote
2-inch PVC Well Screen	40	FT	$8	$300		Century Products, Inc.
2-inch Locking Well Plugs	8	EA	$22	$176		IPS Drilling Quote
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
Drilling Crew Per Diem	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 well
Oversight Labor	50	HR	$80	$4,000		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
<u>**SUBCONTRACT SUBTOTAL**</u>					**$ 3,449,711**	
Payment/Performance Bonds and Insurance (4%)					**$137,988**	
Contractor G&A (12.7%)					**$455,638**	
Contractor Fee (5%)					**$202,167**	
Contractor Professional/Technical Services					**$655,445**	
Project Management	5%			$172,486		USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%			$275,977		USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%			$206,983		USEPA 2000, p. 5-13, $2M-$10M
Contractor Program Management					**$1,183,900**	
Program Management Oversight	2.5%			$122,524		
Contingency	25%			$1,061,376		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$6,084,848**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Groundwater MNA Sampling and Effectiveness Monitoring (In addition to monitoring already planned for alternatives G3b or G3c)					**$6,928**	
GW MNA Samples	4	EA	$406	$1,624		
QC Samples	4	EA	$406	$1,624		
Groundwater Sampling Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Equipment - meters	1	LS	$500	$500		
Consumables	1	LS	$200	$200		CH2M Est.
Data Validation	8	HRS	$80	$640		CH2M Est.
Reporting	8	HRS	$80	$640		CH2M Est.
Allowance for Misc. Items	20%				**$1,386**	
Contingency	30%				**$2,078**	10% Scope + 20% Bid
Project Management	10%				**$693**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$173**	
<u>**SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST**</u>					**$11,258**	
TOTAL ANNUAL O&M COST Year 0 to 30					**$11,258**	

PERIODIC COSTS (INCLUDED IN COSTS FOR BASE ALTERNATIVES G3b or G3c)

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$0**	
5 year Review	5	1	LS	$0	$0		
5 year Review	10	1	LS	$0	$0		
5 year Review	15	1	LS	$0	$0		
5 year Review	20	1	LS	$0	$0		
5 year Review	25	1	LS	$0	$0		
5 year Review	30	1	LS	$0	$0		
TOTAL PERIODIC COST						**$0**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE	TOTAL	NOTES
CAPITAL COST	0	$6,084,848	$6,084,848	1.000	$6,084,848		
ANNUAL O&M COST	1 to 30	$337,740	$11,258	12.41	$139,701		
PERIODIC COST	5	$0	$0	0.71	$0		
PERIODIC COST	10	$0	$0	0.51	$0		
PERIODIC COST	15	$0	$0	0.36	$0		
PERIODIC COST	20	$0	$0	0.26	$0		
PERIODIC COST	25	$0	$0	0.18	$0		
PERIODIC COST	30	$0	$0	0.13	$0		
		$6,422,588			$6,224,549		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$6,220,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G7**
Name: **Air Sparge Curtain**

COST ESTIMATE SUMMARY

Site: OMC Plant 2 (Operable Unit #4) Superfund Site, Waukegan, IL
Location: Groundwater
Phase: Supplemental Feasibility Study Report
Base Year: 2008
Date: 7/31/2008 10:37

Description: 700 foot long HDD screened well (1,000 foot total installation length)
Depth approximately 20-25 feet below ground surface
Air compressor system, housed in small structure onsite with controls
Four additional groundwater monitoring wells in addition to existing network to monitor effectiveness
Long term O&M

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Pre-Construction Activities					**$10,950**	
Survey	1	LS	$10,950	$10,950		CH2M HILL Est.
Construction Activities					**$369,836**	
Pre-Construction Submittals	1	LS	$10,950	$10,950		CH2M HILL Est.
Utility Location	1	LS	$2,738	$2,738		Engineer's Estimate
Installation of HDD biosparge well to 20 feet bgs*	1000	LF	$181	$180,675		Based on verbal estimate by DTD (including decon, IDW contanerization, and well develop)
HDPE Casing (4" HDPE) + freight	300	LF	$9	$2,628		Based on verbal estimate by PQ Products
HDPE Custom Slotted Well Screen + freight	700	LF	$15	$10,731		Based on verbal estimate by PQ Products
HDPE Conveyance Piping Materials, Trenching, and Installation	250	LF	$49	$12,319		Engineer's Estimate
Transport & Disposal of Soil Cuttings	1	LS	$5,256	$5,256		(2) 20CY rolloffs with transport & disposal
50 HP Screw Air Compressor, 200 gallon receiver, condensate system, etc	1	ea	$20,258	$20,258		Based on verbal estimate by Onion Equipment
8' x 20' Shipping Container and Interior Manifold	1	ea	$21,900	$21,900		Based on verbal estimate by Onion Equipment
Electrical Power Drop, 460 V/3 ph/200 A Service, Transformers, Poles	1	LS	$32,850	$32,850		Engineer's Estimate
Final Electrical Connections, Installation of Service Panel and Disconnect	1	LS	$8,760	$8,760		Engineer's Estimate
Equipment Delivery	1	LS	$6,570	$6,570		Engineer's Estimate
Site Restoration	1	LS	$2,738	$2,738		Engineer's Estimate
Misc Piping, Fittings, Materials	1	LS	$2,738	$2,738		Engineer's Estimate
Post Construction Site Survey	1	LS	$2,738	$2,738		Engineer's Estimate
Site Restoration	1	LS	$8,213	$8,213		CH2M HILL Est.
Post Construction Submittals	1	LS	$27,375	$27,375		Including construction completion report
Startup labor	1	week	$7,884	$7,884		
Startup Equipment Rental	1	week	$329	$329		
Startup Travel and Perdiem	1	week	$2,190	$2,190		
Additional Monitoring Well Installation					**$33,124**	
Mobilization/Demobilization	1	LS	$15,000	$15,000		Includes submittals
Hollow-Stem Auger Drilling (4.25" ID)	180	FT	$27	$4,860		4 shallow and 4 deep wells/area
2-inch PVC Well Casing	140	FT	$4	$588		IPS Drilling Quote
2-inch PVC Well Screen	40	FT	$8	$300		IPS Drilling Quote
2-inch Locking Well Plugs	8	EA	$22	$176		0
Monitoring Well Completion - Flush	8	EA	$250	$2,000		IPS Drilling Quote
Monitoring Well Development	8	EA	$400	$3,200		Project Exper
Drilling Crew Per Diem	5	DY	$400	$2,000		1 crew per day, 1 deep and 2 shallow locations per day plus 4 wells/day for development
Oversight Labor	50	HR	$80	$4,000		CH2M HILL 1 person
Oversight Per Diem	5	DY	$200	$1,000		CH2M HILL 1 person
SUBCONTRACT SUBTOTAL					**$413,910**	
Payment/Performance Bonds and Insurance (4%)					**$16,556**	
Contractor G&A (12.7%)					**$54,669**	
Contractor Fee (5%)					**$24,257**	
Contractor Professional/Technical Services					**$136,590**	
Project Management	8%			$33,113		USEPA 2000, p. 5-13, $100K - $500K
Remedial Design	15%			$62,087		USEPA 2000, p. 5-13, $100K - $500K
Construction Management	10%			$41,391		USEPA 2000, p. 5-13, $100K - $500K
Contractor Program Management					**$143,498**	
Program Management Oversight	2.5%			$16,150		
Contingency	25%			$127,348		10% Scope + 15% Bid
TOTAL CAPITAL COST					**$789,481**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Annual System O&M					**$70,100**	
Misc Field Operations, Compliance, Safety, Optimization, Tasks	1	LS	$25,000	$25,000		
Weekly System Checks for First Month	4	events	$650	$2,600		
Monthly Gauging and Compressor Maintenance	12	events	$1,000	$12,000		
Quarterly "Heavy" Maintenance	4	events	$1,000	$4,000		
O&M Supplies	1	LS	$2,000	$2,000		
Electrical usage ($0.075/kw-hr, 80 hp peak motor rating)	1	year	$24,500	$24,500		
Allowance for Misc. Items	20%				**$14,020**	
Contingency	30%				**$21,030**	10% Scope + 20% Bid
Project Management	10%				**$7,010**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$1,753**	
SUBTOTAL ANNUAL O&M COST					**$113,913**	
Groundwater MNA Sampling and Effectiveness Monitoring (In addition to monitoring already planned for alternatives G3b or G3c)					**$11,456**	
GW MNA Samples	8	EA	$406	$3,248		
QC Samples	8	EA	$406	$3,248		
Groundwater Sampling Labor	20	HRS	$85	$1,700		2 people, 1 days, 10 hr/day
Equipment - meters	1	LS	$500	$500		
Consumables	1	LS	$200	$200		CH2M Est.
Data Validation	16	HRS	$80	$1,280		CH2M Est.
Reporting	16	HRS	$80	$1,280		CH2M Est.
Allowance for Misc. Items	20%				**$2,291**	
Contingency	30%				**$3,437**	10% Scope + 20% Bid
Project Management	10%				**$1,146**	USEPA 2000, p. 5-13, <$100 K
Program Management Oversight	2.5%				**$286**	
SUBTOTAL ANNUAL GROUNDWATER SAMPLING COST					**$18,616**	
TOTAL ANNUAL O&M COST Year 0 to 30					**$132,529**	

PERIODIC COSTS (INCLUDED IN COSTS FOR BASE ALTERNATIVES G3b or G3c)

DESCRIPTION		QTY	UNIT	UNIT COST	SUBTOTAL	TOTAL	NOTES
Reporting						**$0**	
5 year Review	5	1	LS	$0	$0		
5 year Review	10	1	LS	$0	$0		
5 year Review	15	1	LS	$0	$0		
5 year Review	20	1	LS	$0	$0		
5 year Review	25	1	LS	$0	$0		
5 year Review	30	1	LS	$0	$0		
TOTAL PERIODIC COST						**$0**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

COST TYPE	YEAR	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE		NOTES
CAPITAL COST	0	$789,481	$789,481	1.000	$789,481		
ANNUAL O&M COST	1 to 30	$3,975,855	$132,529	12.409	$1,644,552		
PERIODIC COST	5	$0	$0	0.71	$0		
PERIODIC COST	10	$0	$0	0.51	$0		
PERIODIC COST	15	$0	$0	0.36	$0		
PERIODIC COST	20	$0	$0	0.26	$0		
PERIODIC COST	25	$0	$0	0.18	$0		
PERIODIC COST	30	$0	$0	0.13	$0		
		$4,765,336			$2,434,032		
TOTAL PRESENT VALUE OF ALTERNATIVE						**$2,430,000**	Value rounded to nearest $10,000.

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Appendix C

CSU Bench-Scale Evaluation Report and Addendum

FINAL REPORT

Bench-Scale Evaluation of ZVI-Clay
OMC Plant 2
Waukegan, Illinois

Developed by

Colorado State University
Center for Contaminant Hydrology

For
CH2M HILL, Inc.

June 5, 2006

Report Contents

1.0 Executive Summary 3
2.0 Disclaimer 4
3.0 Introduction 5
3.1 Technology Description 5
4.0 Methods 6
4.1 Materials Receipt and Preparation 6
4.2 Batch Reactor Study...6
4.2.1. Experimental Design 6
4.2.2. Batch Reactor Construction 8
4.2.3. Soil Preparation 8
4.2.4. Grout Preparation 8
4.2.5. Soil Mixing Procedures 9
4.2.6. Sampling and Analysis..10
4.2.7. Post Treatment Analyses 11
5.0 Results 12
5.1 Batch Reactor Study Performance Data..12
5.1.1. Iron Source and Amount 12
5.1.2. Addition of $NaHCO_3$ 14
5.1.3. Addition of Cement 15
5.1.4. Reaction Kinetics 15
5.1.5. Chloride Formation 16
5.1.6. Iron Content 17
5.1.7. pH and Oxidation/Reduction Potential 18
5.1.8. QA/QC 18
5.2 Gas Generation 19
5.3 Unconfined Compressive Strength...20
6.0 References..21

1.0 Executive Summary

The work described in the following report was conducted by Colorado State University (CSU) in support of an evaluation of ZVI-Clay technology for soil remediation at OMC Plant 2 in Waukegan, Illinois (Site). Objectives of the work include (1) demonstrating the effectiveness of ZVI-Clay to degrade site-specific contaminants of concern, (2) resolving the relative effectiveness of Peerless, GMA, and QMP iron at application rates of 1 and 3%, (3) investigating the treatment performance with addition of sodium bicarbonate and cement (local source of off-specification product), and (4) evaluating the use of cement to improve post treatment soil strength. A bench scale study was completed by CSU to evaluate ZVI-Clay based on these objectives. This report provides methods, results, and conclusions drawn from the study.

Site samples of soil, groundwater, and NAPL were collected by CH2M Hill and shipped to CSU. In preparation for the study, site soils were saturated with groundwater, spiked with NAPL, and homogenized. The homogeneous soil sample was then loaded into 14 batch reactor vessels. A bench-scale mixing apparatus was used to mix soils within the reactors and deliver treatments into the soil. Following treatment via soil mixing, performance was monitored via soil samples collected after 0, 3, 14, 28, and 59 days. Soil samples were analyzed for chlorinated contaminants of concern (e.g., TCE). Other relevant treatment parameters were monitored including chloride concentration, pH, and oxidation/reduction potential.

The primary contaminant detected was TCE, with an initial concentration of approximately 350 mg/kg. In general, GMA achieved fastest degradation of TCE, followed by Peerless, then QMP. Faster reaction kinetics were achieved through use of 3% versus 1% iron. Use of 1% and 3% GMA iron reduced TCE to 48 mg/kg and 0.11 mg/kg, respectively. Use of 1% and 3% Peerless iron reduced TCE to 190 mg/kg and 12 mg/kg, respectively. Use of 1% and 3% QMP iron reduced TCE to 220 mg/kg and 89 mg/kg, respectively. Other results included:

- Sodium bicarbonate addition (0.5%) did not significantly impact treatment.
- Cement addition (1%, local source) significantly inhibited the reaction rate.

Other parameters including pH, ORP, and chloride concentrations provided evidence that TCE depletion is in fact due to iron-mediated reductive dechlorination. Faster depletion in the treated soil versus in the no-iron control also indicates that iron is driving degradation.

2.0 Disclaimer

Colorado State University provides no guarantees or warranties regarding the performance of the ZVI-Clay technology at a field scale or over extended periods. Parties utilizing information presented herein should recognize the following:

1. Conditions in the field can vary from those in the laboratory;
2. Performance observed during the relatively short duration of the laboratory studies does not guarantee long-term performance;
3. All aspects of the ZVI-Clay treatment processes are not fully understood at this time; and
4. Success at a field scale will be highly dependent on field delivery and mixing of reactive media, stabilizing agents, and target compounds.

3.0 Introduction

The following has been developed per the request of CH2M HILL. The described work was conducted in support of an evaluation of ZVI-Clay technology for treatment of contaminated soils at OMC Plant 2 in Waukegan, Illinois. Objectives of the work include:

1. Demonstrating the effectiveness of ZVI-Clay to degrade trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), and related degradation products in site soils;

2. Resolving the relative effectiveness of Peerless, GMA, and QMP iron at application rates of 1 and 3 percent by dry weight soil;

3. Investigating the effectiveness of sodium bicarbonate and cement (local source of off-specification product) to control low pH condition that could drive excess generation of hydrogen gas; and

4. Evaluating the use of cement to improve post treatment soil strength.

The following presents a final report outlining methods and results.

3.1 Technology Description

ZVI-Clay uses conventional soil mixing equipment to admix reactive media (e.g., ZVI) and stabilizing agents (e.g., clay) with contaminated soil. Reactive media and stabilizing agents are combined in a grout, which is delivered into contaminated soils via a port in the soil-mixing tool (Day and Ryan 1995). Through mixing, heterogeneous subsurface source zones are transformed into uniform bodies of soils, contaminants, reactive media, and stabilizing agents. Within the treated interval, two levels of treatment are achieved: (1) reactive media drives contaminant degradation, while (2) stabilizing agents reduce the hydraulic conductivity. In addition, soil mixing overcomes the challenge of delivering reactive media through complex geologic media. The envisioned benefit of ZVI-Clay treatment is a reduction in contaminant flux from the treated interval.

4.0 Methods

4.1 Materials Receipt and Preparation

Soil cores from the site were collected by CH2M HILL and shipped to CSU in December 2006. Additional materials received by CSU in December 2006 included cement (off-spec product from a source near the site), fly ash (not used in the study), and groundwater and NAPL samples collected from the site. A summary of shipments received is shown in Table 1. In all, 225 pounds of soil were received by CSU. Most of the soils were used in the batch reactor study (see below); approximately 2 gallons of soils were retained for archive purposes.

Table 1: Summary of Materials Received

Date received	Shipment	Contents
12/14/06	3 Coolers	Soil
12/22/06	3 Coolers	Water, NAPL, cement, and kiln dust

Soil cores were processed by CSU on December 22, 2006. Related activities included opening of soil cores, logging soils for physical properties, and dividing samples for subsequent studies. During soil logging, soils were screened for VOCs using an Organic Vapor Analyzer (OVA). Select samples with elevated OVA readings were checked for the presence of NAPL using Sudan IV. Soils were added to a 40-mL vial with water and Sudan IV, a NAPL-soluble dye. None of the analyzed samples were found to contain NAPL using the Sudan IV screening method. A spreadsheet describing observed soil properties is presented in Appendix A.

Groundwater and NAPL samples were stored at 4^{o}C. As described in detail below, groundwater was used to saturate site soils prior to treatment. Site NAPL was added to the soils to spike concentration levels prior to treatment. Liquids added to the soil included 3 liters of site groundwater and 130 mL of NAPL.

4.2 Batch Reactor Study

Batch reactor studies were conducted to evaluate effectiveness using various treatments. The scope of this work included construction of 14 batch column reactors, soil preparation, grout preparation, soil mixing, and sampling. This section describes the work in detail.

4.2.1. Experimental Design

A summary of columns prepared and mixed is shown in Table 2. The experimental design matrix is shown in Figure 1. Except for the unmixed control (column W-1), 1% bentonite clay was added to all columns.

Table 2: Summary of Batch Reactor Columns

Column ID	Description	Iron Amount*	Iron Source	Bentonite Added*	Other Treatment
W-1	Unmixed control	-	-	-	-
W-2	Mixed control	-	-	1%	-
W-3	ZVI-Clay (1%)	1%	Peerless	1%	-
W-4	ZVI-Clay (1%)	1%	GMA	1%	-
W-5	ZVI-Clay (1%)	1%	QMP	1%	-
W-6	ZVI-Clay (3%)	3%	Peerless	1%	-
W-7	ZVI-Clay (3%)	3%	GMA	1%	-
W-8	ZVI-Clay (3%)	3%	QMP	1%	-
W-9	ZVI-Clay ($NaHCO_3$)	1%	Peerless	1%	0.5% $NaHCO_3$
W-10	ZVI-Clay ($NaHCO_3$)	1%	GMA	1%	0.5% $NaHCO_3$
W-11	ZVI-Clay ($NaHCO_3$)	1%	QMP	1%	0.5% $NaHCO_3$
W-12	ZVI-Clay (cement)	1%	Peerless	1%	1% Cement
W-13	ZVI-Clay (cement)	1%	GMA	1%	1% Cement
W-14	ZVI-Clay (cement)	1%	QMP	1%	1% Cement

Notes:
**** Percents indicate mass of material per mass of total dry solids***

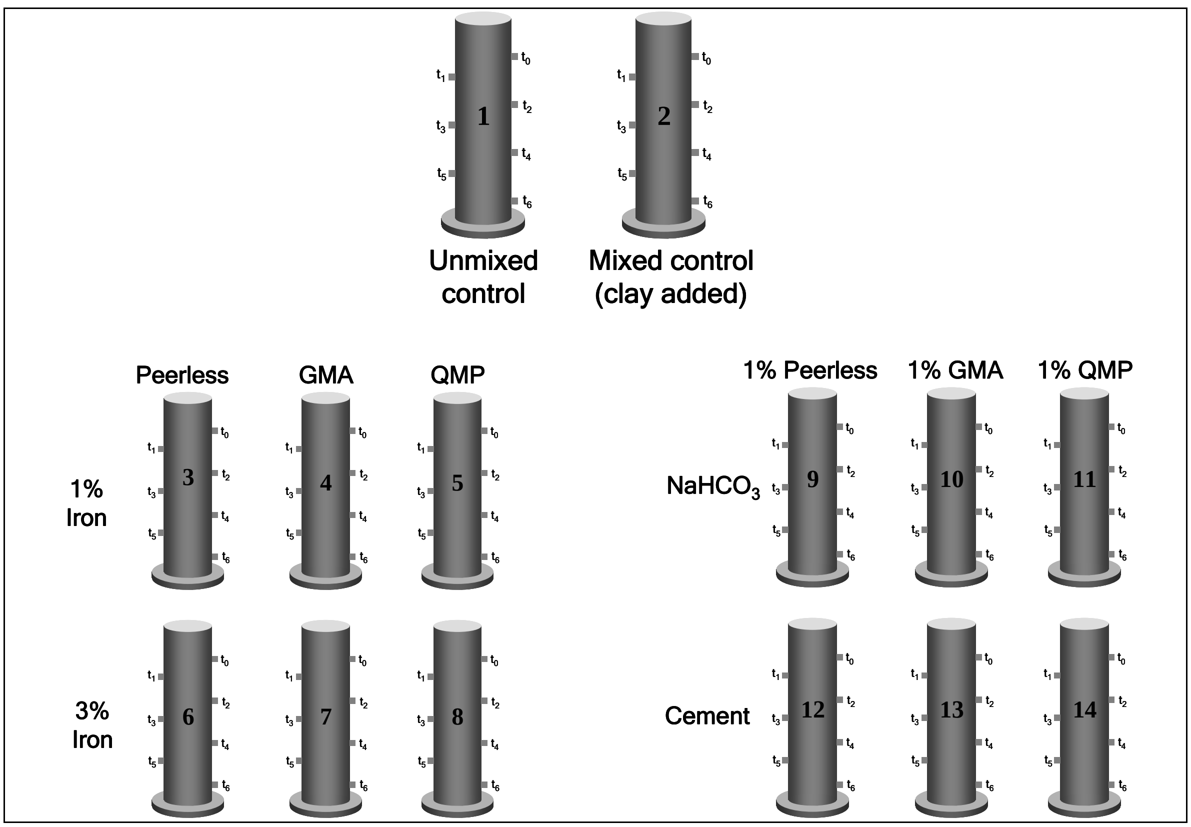

Figure 1: Experimental Design Matrix

4.2.2. Batch Reactor Construction

A photograph of the batch reactor column is shown in Figure 2. The batch reactors used in the study are 40 centimeters in height, 10-cm in diameter, and are constructed of schedule 40 transparent PVC. Sampling ports sealed with Nylon plugs are located at 5-cm intervals along the wall of the column. The top of each column is sealed using a Cherne Monitor-Well plug. The bottom of the column is cemented into a PVC flange; this flange is bolted onto an acrylic sheet to seal the column.

Figure 2: Columns Used for Study: Empty (left) and Filled with Soil.

4.2.3. Soil Preparation

Steps to prepare soils for treatment include homogenization and “spiking”. Homogenization was accomplished using a hand-held drill and paint mixing tool. During homogenization, 3 liters of site water were added to the soil to fully saturate the soils and facilitate mixing. Following homogenization, soils were spiked with the non-aqueous phase liquid (NAPL) sample collected from the site. NAPL was added to the soils in 10 mL increments using a syringe and 9-inch needle. All of the provided NAPL, approximately 130 mL, was added to the soil. Following each DNAPL injection, the soils were vigorously blended using a hand-held drill and paint mixing tool. Blending was repeated over 3 days to ensure homogenization. Once spiking was complete, the soils were loaded into the reactor columns shown in Figure 2.

4.2.4. Grout Preparation

In addition to performing as a drilling fluid, the grout provides a medium for delivery of the iron and clay into the soil matrix. Prior to mixing of each column, a grout mixture was prepared with tap water, clay, iron, and other reagents (e.g., cement or $NaHCO_3$) per the design matrix. The ZVI-Clay grout mixture was delivered into contaminated soils via a positive displacement pump connected to the soil-mixing tool. Detailed compositions of the ZVI-Clay grout mixture used for each column are shown in Appendix B.

4.2.5. Soil Mixing Procedures

Treatment of the columns was completed using the soil-mixing platform shown in Figure 3. The mixing apparatus advances the soil-mixing auger through the columns at a fixed vertical velocity and rate of rotation. The grout is delivered at a controlled rate through a port in the soil-mixing tool. The apparatus is designed to emulate field mixing techniques and achieve repeatable mixing results in a laboratory setting.

Mixing in each column was completed in three down-up passes. ZVI-Clay grout was delivered during the downward portion of the first pass; subsequent passes were completed to achieve a more uniform mixture. Total time to mix each column is about 20 minutes.

Immediately after mixing, the column was sealed as quickly as possible. Tasks completed prior to sealing the column include collection of an initial sample and installation of a gas collection apparatus (Figure 4). In general, the columns were sealed within 5 minutes of completion of mixing and remained sealed throughout the experiment.

Figure 3: Mixing Apparatus – Platform (left) and Soil-Mixing Auger (right)

Figure 4: Gas collection apparatus.

4.2.6. Sampling and Analysis

Soil samples were collected after approximate reaction times of 0, 3, 7, 28, and 56 days. *Time 0* samples were collected from the top of the columns immediately after mixing. Subsequent soil samples were collected from the sampling ports. Soil samples were collected using coring tubes (Figure 5). Upon collection, soil samples were immediately extruded from the coring tube into a vial containing 10 milliliters of MTBE extractant. The soil/extractant mixture was then agitated for approximately one hour using a sieve shaker. Duplicate samples were collected at an approximate frequency of 10%.

Figure 5: Collecting soil samples using a 1-cm diameter coring tube

Samples were analyzed for chlorinated volatile organic compounds (CVOCs) including TCE, PCE, and 1,1,1-TCA. Analysis was conducted on a Hewlett Packard 5890 Series II gas chromatograph (GC) with an Agilent DB-624 column and electron capture detector (ECD).

Soil samples were analyzed for chloride concentration and water content. Water content is used to convert soil concentrations to a dry soil basis. Each sample collected for soil concentration data was analyzed for water content. Water content was measured by heating the samples at 110^{o}C until a constant sample mass was achieved. These parameters were measured in all samples at the end of the experiment.

4.2.7. Post Treatment Analyses

Following collection of the 56-day samples, each column was monitored for chloride concentration, pH, and Oxidation/Reduction Potential (ORP). These parameters provide evidence that reducing conditions are present in the columns and that reductive dechlorination is indeed occurring. Chloride (Cl^-) is released during reductive dechlorination; an increase in chloride in treated columns verifies that contaminants are being dechlorinated. Following completion of the batch reactor study, a sample was removed from each column for chloride analysis. Chloride analysis was performed using an ion-specific electrode (ISE) that was calibrated in 5, 50, and 500 mg/L (as Cl^-) NaCl standard solutions prior to use. pH and ORP values can indicate whether reducing conditions are indeed present in the columns, providing further evidence that iron-mediated degradation is occurring. pH was measured using a combination electrode that was calibrated in pH 4 and 7 buffer solutions. ORP was measured using a combination electrode with 4M Ag/AgCl reference solution. Measured redox potentials were converted to a Standard Hydrogen Electrode basis.

Soil compressive strength was measured for three samples. The proposal stated that unconfined compressive strength would be measured using soil cores removed from the columns after completion of the batch reactor study. However, it was determined that soils removed from the batch reactors are not suitable for this test due to uncontrolled sample water content. As such, separate samples were prepared for testing using archived site soils. In preparation, site soils were dried in an oven at 110^{o}C to remove water. Dried soils were then passed through a number 10 sieve to remove coarse particles. Samples were prepared with 1% bentonite clay and a water content (calculated as mass of water per mass of dry soil) of 18%. Amendments to the three samples included (1) no additional amendments, (2) 1% cement addition, and (3) 0.5% $NaHCO_3$ addition. Methods used for unconfined compressive strength were based on ASTM D2166.

5.0 Results

5.1 Batch Reactor Study Performance Data

The following section presents related results for various iron amounts and sources, cement addition, and $NaHCO_3$ addition in each of the batch reactor columns. A complete listing of measured concentrations is included in Appendix C. Soil concentrations are presented in mass of contaminant per mass of dry soil.

Site specific contaminants of concern were monitored over time. Soils were initially spiked with NAPL provided from the site. TCE was the primary component of the provided NAPL. 1,1,1-TCA was not detected in site soils after addition of NAPL. Small levels of PCE (generally less than 0.2 mg/kg) were also detected. TCE daughter products were not found above quantifiable detection limits.

It is noted that time 0 samples, which were collected immediately after each column was mixed, were collected through the top of the column prior to placing the lid and sealing the column. These values appear low in most columns; there (incorrectly) appears to be a concentration increase from time 0 to 3 days in many cases. These samples are likely biased due to atmospheric exposure during mixing. In future studies, collection of time 0 samples will employ the same technique as subsequent sampling, i.e., through sample ports in the side of the column.

5.1.1. Iron Source and Amount

Iron was evaluated from three sources (Peerless, GMA, and QMP) and in two amounts (1% and 3% of the dry soil weight). Soil results for columns containing 1% iron from all three sources is shown in Figure 6. After 56 days, the best results were obtained using GMA iron, with concentrations reduced to 48 mg/kg. Fifty-six day TCE concentrations were reduced to 190 mg/kg using 1% Peerless and 220 mg/kg using 1% QMP iron.

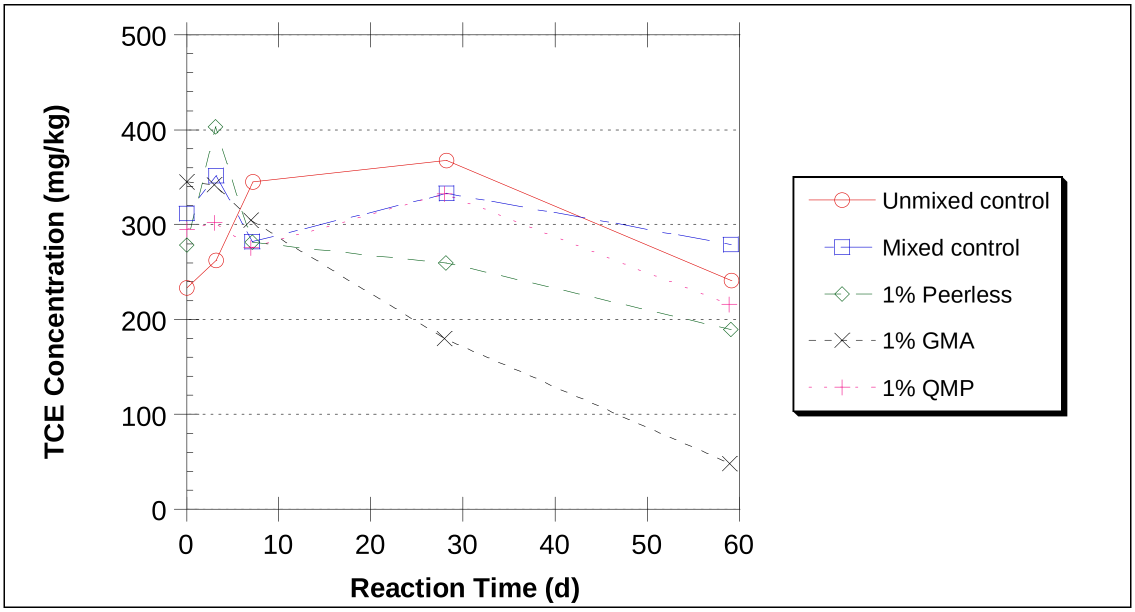

Figure 6: Results from samples containing 1% iron

Results for all columns containing 3% iron are shown in Figure 7. Treatment in these columns clearly proceeded at a faster rate than columns containing 1% iron. In the column containing 3% GMA iron, TCE was reduced to 0.11 mg/kg over the 56-day study. Final TCE concentrations were reduced to 12 mg/kg using 3% Peerless and 89 mg/kg using 3% QMP iron.

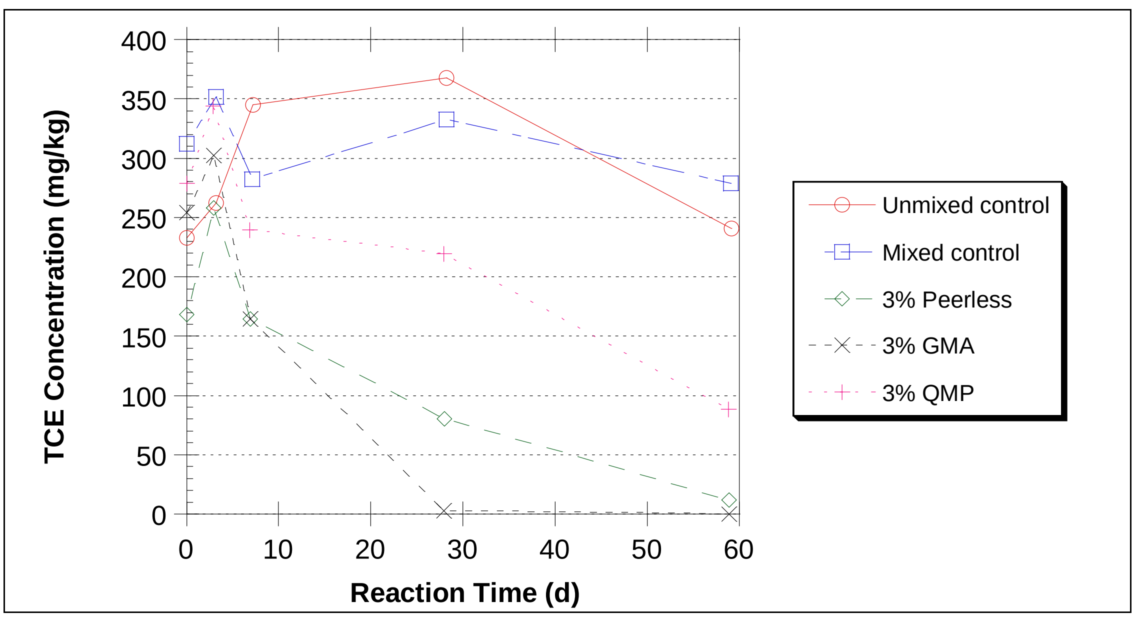

Figure 7: Results from samples containing 3% iron

5.1.2. Addition of $NaHCO_3$

Results for the three columns prepared with sodium bicarbonate ($NaHCO_3$) are shown in Figure 8. Sodium bicarbonate columns were prepared with 1% iron from each source. Figure 9 shows a comparison of results for respective columns prepared with and without $NaHCO_3$ (i.e., columns containing 1% iron). Addition of $NaHCO_3$ did not appear to significantly affect TCE degradation rates.

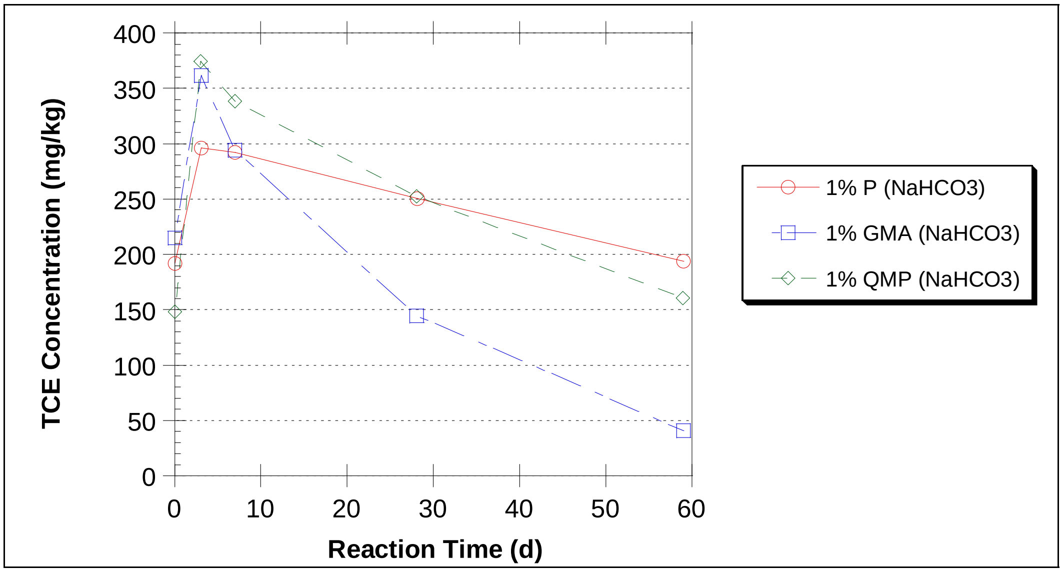

Figure 8: Results from samples containing 1% iron and 0.5% sodium bicarbonate ($NaHCO_3$).

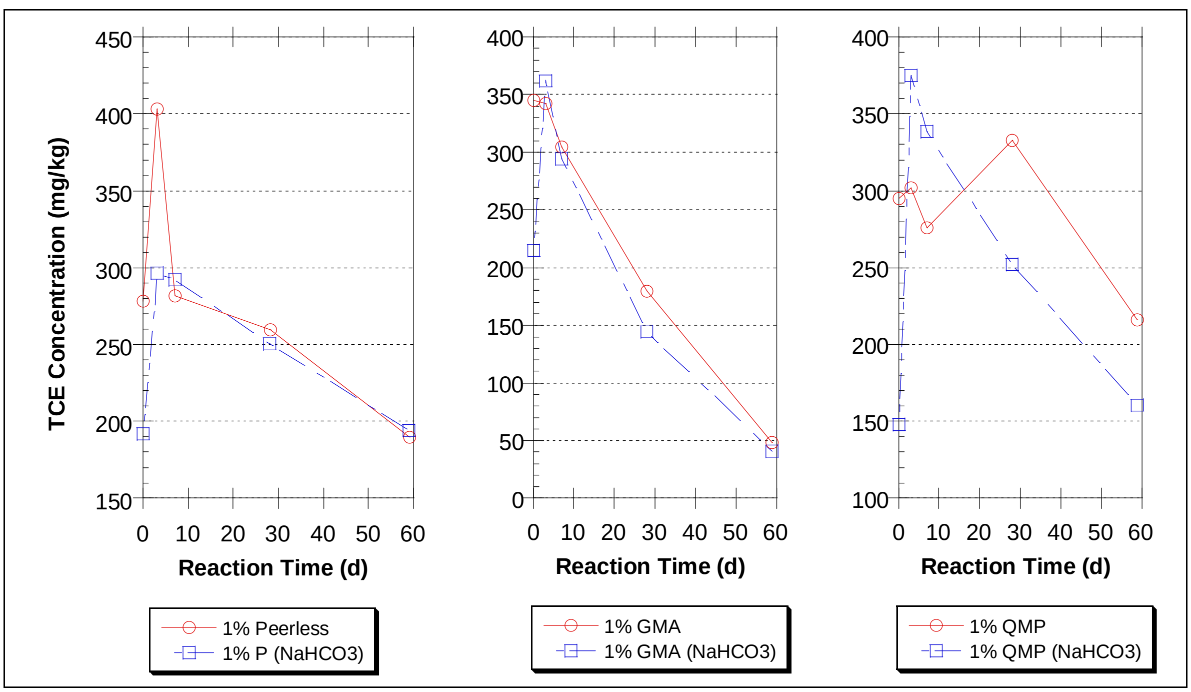

Figure 9: Comparison of treatment results with and without addition of sodium bicarbonate. All columns were treated with 1% iron from the source indicated.

5.1.3. Addition of Cement

Three columns were prepared with 1% cement to evaluate treatment performance. In previous studies conducted by CSU, greater amounts of cement had been added and were found to significantly hinder reaction performance. Our hope was that inclusion of 1% cement would improve soil strength without hindering reaction. The cement used, provided by CH2M Hill, was an off-specification product from a location local to the site.

Results for columns prepared with cement are shown in Figure 10. A slight decrease is noted over the 56-day study. However, the reaction rate is clearly affected by inclusion of 1% cement.

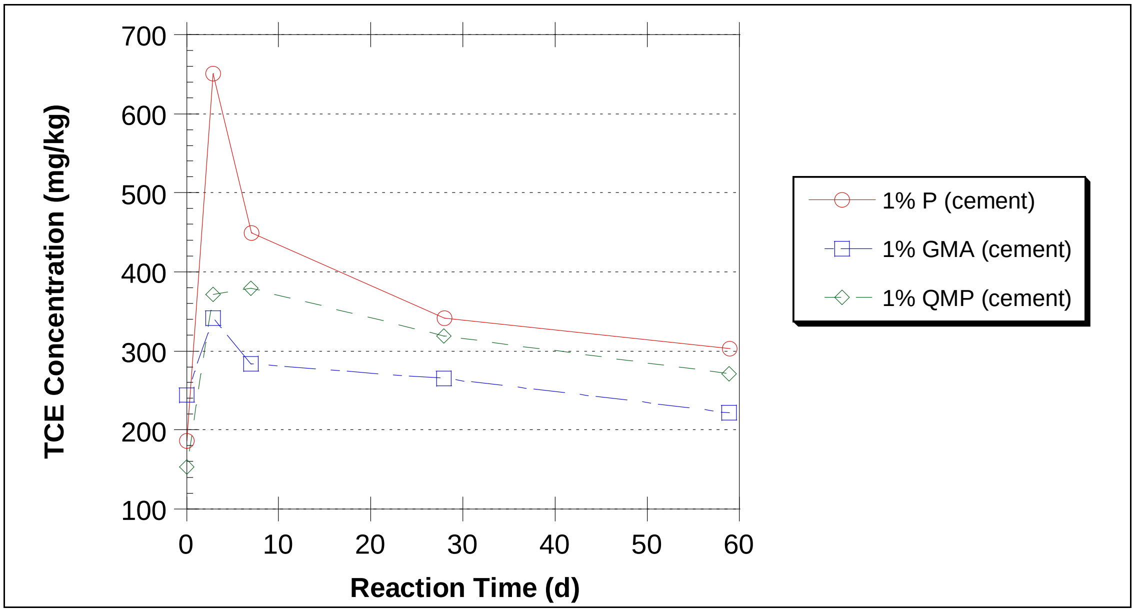

Figure 10: Results from samples containing 1% iron and 1% cement.

5.1.4. Reaction Kinetics

A useful method for comparison of different treatments is the half-life. Half-lives allow for comparison of relative degradation rates using a single number. As such, half-lives provide a means for easier comparison of different treatments for their ability to degrade certain contaminants. Half-lives can also be extrapolated to provide a rough prediction of performance over time.

Contaminant half-lives were estimated using pseudo-first order assumptions. A summary of half-lives for primary contaminants for each column is shown in Table 3.

Table 3: Estimated Contaminant Half-Lives (Days) for Each Treatment.

Column ID	Description	TCE Half-Life (days)
W-1	Unmixed control	210
W-2	Mixed control	301
W-3	1% Peerless	63
W-4	1% GMA	20
W-5	1% QMP	141
W-6	3% Peerless	13
W-7	3% GMA	5
W-8	3% QMP	32
W-9	1% P ($NaHCO_3$)	90
W-10	1% GMA ($NaHCO_3$)	18
W-11	1% QMP ($NaHCO_3$)	47
W-12	1% P (cement)	95
W-13	1% GMA (cement)	108
W-14	1% QMP (cement)	116

5.1.5. Chloride Formation

Reductive dechlorination results in formation of chloride (Cl^-). Chloride was monitored to provide verification that reductive dechlorination is indeed occurring. Results are presented in Table 4.

Table 4: Measured chloride concentrations.

Column ID	Description	Chloride concentration (mg/kg)
W-1	Unmixed control	41
W-2	Mixed control	28
W-3	1% Peerless	243
W-4	1% GMA	370
W-5	1% QMP	76
W-6	3% Peerless	386
W-7	3% GMA	423
W-8	3% QMP	278
W-9	1% P ($NaHCO_3$)	159
W-10	1% GMA ($NaHCO_3$)	228
W-11	1% QMP ($NaHCO_3$)	135
W-12	1% P (cement)	35
W-13	1% GMA (cement)	54
W-14	1% QMP (cement)	66

Elevated chloride concentrations are found in columns of most effective treatment. In particular the measured Cl^- levels in columns containing 3% iron (W-6, W-7, and W-8) are higher than respective columns with less iron. Final Cl^- levels in columns containing cement are much closer to those measured in the untreated control columns, indicating that little Cl^- generation has occurred. Measured chloride data presents evidence that reductive dechlorination is occurring.

5.1.6. Iron Content

Iron content was measured at the conclusion of the batch reactor study. Samples were pulled from columns for iron analysis following collection of 56-day samples. Measured iron concentrations are shown in Table 5. These values represent a snapshot of iron remaining at the end of the experiment.

It is noted that the unmixed and mixed control columns, to which no iron was initially added, were found to contain 0.3% and 0.5% iron, respectively. In addition, some columns contained more iron than was initially added (columns W-6, W-9, W-10, and W-12). Through inspection of the magnetically separated material it was found that some of the site media probably contained magnetic iron and was therefore separated with the added ZVI. That said, measured iron contents generally correlate well with initial values and provide verification that ZVI was indeed delivered into the soils.

Table 5: Iron Remaining at End of Experiment.

Column ID	Description	Target Iron Content[1]	Iron Source	Final Iron content
W-1	Unmixed control	-	-	0.3%
W-2	Mixed control	-	-	0.5%
W-3	1% Peerless	1%	Peerless	0.8%
W-4	1% GMA	1%	GMA	0.8%
W-5	1% QMP	1%	QMP	0.9%
W-6	3% Peerless	3%	Peerless	3.3%
W-7	3% GMA	3%	GMA	2.5%
W-8	3% QMP	3%	QMP	1.9%
W-9	1% P ($NaHCO_3$)	1%	Peerless	1.2%
W-10	1% GMA ($NaHCO_3$)	1%	GMA	1.8%
W-11	1% QMP ($NaHCO_3$)	1%	QMP	1.0%
W-12	1% P (cement)	1%	Peerless	1.1%
W-13	1% GMA (cement)	1%	GMA	0.7%
W-14	1% QMP (cement)	1%	QMP	1.0%

5.1.7. pH and Oxidation/Reduction Potential

pH and Oxidation/Reduction Potential (ORP) were measured in each column at the concusion of the experiment. ORP values were measured relative to a 4M Ag/AgCl reference solution. Reported values are converted to Standard Hydrogen Electrode (SHE). Measured values are shown in Table 6.

Low ORP values in treated columns indicate that reducing conditions are indeed present in treated columns. From a comparison of ORP values in ZVI-treated columns versus untreated control columns, iron appears to be driving the reducing conditions.

Table 6: pH and ORP in each column.

Column ID	Description	ORP (SHE, mV)	pH
W-1	Unmixed control	+352	7.58
W-2	Mixed control	+320	7.72
W-3	1% Peerless	-290	7.42
W-4	1% GMA	-380	7.30
W-5	1% QMP	-375	7.74
W-6	3% Peerless	-422	7.68
W-7	3% GMA	-415	7.61
W-8	3% QMP	-408	7.73
W-9	1% P ($NaHCO_3$)	-468	9.00
W-10	1% GMA ($NaHCO_3$)	-514	9.72
W-11	1% QMP ($NaHCO_3$)	-460	9.05
W-12	1% P (cement)	+70	12.10
W-13	1% GMA (cement)	-8	12.20
W-14	1% QMP (cement)	+55	12.41

5.1.8. QA/QC

Quality analysis/quality control (QA/QC) included collection of duplicate samples, collected from select columns with 56-day samples. Appendix D shows a comparison of results from samples collected and their respective duplicates. Duplicate sample results indicate no significant issues with repeatability of results.

5.2 Gas Generation

After ZVI-Clay remediation of soils, gas generation has frequently been observed. In previous laboratory studies and field applications, samples of the evolved gas have been analyzed and found to be primarily composed of hydrogen (H_2), which evolves as iron corrodes in water. In previous studies, chlorinated solvents have been a minor component of the gas, generally found in the low parts per million (ppm) range. Other components include dechlorination products such as methane or ethane.

Measured volumes of gas generation are presented in Table 7. In general, more gas evolution is noted in columns of most effective treatment. Values presented should be considered as estimation only. The batch reactors are designed to optimize collection of soil samples; measuring gas generation volumes is of ancillary importance. Gas generation volumes can be influenced by several factors such as column disturbance/pressure release during soil sample collection or blockage in the line connecting the Tedlar bag to the reactor.

Possible benefits of H_2 generation include further degradation of chlorinated solvents via biological or other means. Due to flammability, health and safety aspects of H_2 generation should be considered in ZVI-Clay treatment design.

Table 7: Measured volume of gas evolved from each column

Column ID	Description	Gas Generation (mL)
W-1	Unmixed control	150
W-2	Mixed control	50
W-3	1% Peerless	450
W-4	1% GMA	50
W-5	1% QMP	100
W-6	3% Peerless	50
W-7	3% GMA	> 3000*
W-8	3% QMP	500
W-9	1% P ($NaHCO_3$)	350
W-10	1% GMA ($NaHCO_3$)	450
W-11	1% QMP ($NaHCO_3$)	450
W-12	1% P (cement)	0
W-13	1% GMA (cement)	> 1000*
W-14	1% QMP (cement)	0

Note:
*** The volume of gas evolved exceeded the capacity of the Tedlar bag.**

5.3 Unconfined Compressive Strength

Soil samples were prepared and evaluated for unconfined compressive strength. Three samples were prepared for this analysis: (1) no additives, (2) 1% cement, and (3) 0.5% $NaHCO_3$. All samples were prepared with 1% bentonite clay and a water content of 18%. Results are presented in Table 8. In general, unconfined compressive strength results appear low, even for the sample containing 1% cement. This is likely attributable to the high sand content of the soils. Even with addition of 1% clay, the sand content was high enough that the samples lacked cohesion. As such, these values might not reflect strength values that would be achieved in the field.

Table 8: Unconfined compressive strength measurement results.

Sample No.	Treatments	Results (psi)
1	1% clay	1.3
2	1% clay 1% cement	3.6
3	1% clay 0.5% $NaHCO_3$	0.8

6.0 References

Day, S.R. and C. Ryan. 1995. Containment, Stabilization, and Treatment of Contaminated Soils using In situ Soil Mixing. *Geoenvironment 2000*, ed. Y.B. Acar and D.E. Daniel, 1349-65. Reston, Virginia: American Society of Civil Engineers.

Gillham, R.W., and S.F. O'Hannesin. 1994. Enhanced Degradation of Halogenated Aliphatics by Zero-Valent Iron. *Ground Water* 32, no.6: 958-967.

APPENDIX A: LOGGED SOIL DATA

Sample ID	Location	Sample Interval Top	Sample Interval Bottom	Total Mass (g)	Soil Mass (g)	length (cm)	Density (g/mL)	Media	Sorting	Grain Size	Color	OVA
07CW09-01	200	0	2	1,583	1,407	61.5	1.65	sand	poor	silt, sand, and gravel	tan to brown to black	1.4
07CW09-05	200	2	2.5	468	425	19.5	1.57	sand	well	fine	lt. tan	1.3
07CW09-06	200	4	6	1,724	1,721	61	2.04	sand	well	fine	brown to dark brown	1.4
07CW09-07	200	6	7	1,030	1,030	34	2.19	sand	well	fine	tan	1.5
07CW09-08	200	8	10	2,023	2,023	61	2.39	sand	well	fine	lt. tan	3.9
07CW09-02	200	10	12	1,732	1,732	55	2.27	sand	well	fine	tan	6.1
07CW09-03	200	12	14	2,025	2,025	61	2.40	sand	well	fine	tan	2.5
07CW09-04	200	14	16	1,729	1,729	54	2.31	sand	well	fine	lt. tan	14.7
07CW09-09	200A	0	1	790	790	31	1.84	sand	poor	fine sand to pebbles	reddish brown w/black layer	1.4
07CW09-10	200A	1	2.5	1,227	1,227	43	2.06	sand	well	fine	tan to black	1.4
07CW09-18	200A	4	6	1,857	1,857	59	2.27	sand	mod.	fine	tan	2.7
07CW09-19	200A	8	9	943	943	31.5	2.16	sand	well	fine	tan	1.4
07CW09-20	200A	9	10.3	1,160	1,160	38.5	2.17	sand	well	fine	lt. tan	7.9
07CW09-11	200A	12	14	1,968	1,968	61	2.33	sand	well	fine	brown	15.1
07CW09-12	200A	14	15.7	1,623	1,623	51.5	2.27	sand	well	fine	tan	6.8
07CW09-13	200A	16	17	930	930	31	2.17	sand	well	fine	tan to grey	1.7
07CW09-14	200A	17	18.5	1,482	1,482	48	2.23	sand	mod.	fine to coarse	grey	1.9
07CW09-15	200A	20	22	1,784	1,784	61	2.11	sand	well	fine	grey-brown	1.6
07CW09-17	200A	22	24	1,559	1,559	50	2.25	sand	well	fine	grey	1.3
07CW09-16	200A	22	23.6	1,555	1,555	49.5	2.27	sand	well	fine	grey	2.7
07CW09-21	203	12	14	1,791	1,791	61	2.12	sand	mod.	fine	reddish to lt. to dark brown	
07CW09-22	203	12	14					sand	well	fine	lt. brown	3.1
07CW09-22	203	14	15.6	1,396	1,396	48.5	2.08	sand	well	fine	lt. brown	23.6
07CW09-23	203	16	18	1,939	1,939	60	2.33	sand	well	fine	lt. brown	52.7
07CW09-24	203	18	19.6	1,615	1,615	50	2.33	sand	well	fine	lt. brown	65
07CW09-25	203	20	22	2,006	2,006	62	2.34	sand	well	fine	grey	2.5

APPENDIX A: LOGGED SOIL DATA

Sample ID	Location	Sample Interval Top	Sample Interval Bottom	Total Mass (g)	Soil Mass (g)	length (cm)	Density (g/mL)	Media	Sorting	Grain Size	Color	OVA
07CW09-27	204	0	1	769	769	32	1.73	sand	poor	silt, sand, and gravel	reddish brown	1.4
07CW09-28	204	1	3	1,660	1,660	56.5	2.12	sand	poor	silt, sand, and gravel	tan, black at surface	1.4
07CW09-37	204	4	6	2,011	2,011	61.5	2.36	sand	mod.	fine	light tan to brown	1.4
07CW09-38	204	6	7.4	1,258	1,258	38.5	2.36	sand	mod.	fine	lt. tan	1.3
07CW09-39	204	8	10	1,705	1,705	61	2.02	sand	well	fine	light tan	4
07CW09-29	204	10	12	1,344	1,344	55.5	1.75	sand	well	fine	tan	3.1
07CW09-30	204	12	14	1,899	1,899	61	2.25	sand	well	fine	light tan	44
07CW09-31	204	14	15.7	1,639	1,639	52	2.27	sand	well	fine	lt.tan	12.3
07CW09-32	204	16	18	1,944	1,944	61	2.30	sand	well	fine	tan	90.3
07CW09-33	204	18	19.5	1,504	1,504	47.5	2.29	sand	well	fine	tan	46.1
07CW09-34	204	20	22	1,994	1,994	61	2.36	sand	well	fine	grey	3.3
07CW09-35	204	22	23.6	1,602	1,602	49	2.36	sand	well	fine	grey	5.7
07CW09-36	204	24	27.7					sand	well	fine	grey	4000
07CW09-40	204											
07CW09-41	206	0	2	1,517	1,517	61	1.80	sand	poor	silt, sand, and gravel	brown w/ dark grey layer	1.9
07CW09-44	206	2	3	1,010	1,010	35	2.08	sand	well	fine	tan w/dark layer	1.5
07CW09-47	206	4	6	1,762	1,762	61	2.09	sand	well	fine	tan to dark brown	1.3
07CW09-48	206	8	10	1,822	1,822	61	2.16	sand	well	fine	tan	
07CW09-42	206	10	11.5	1,406	1,406	48	2.11	sand	well	fine	tan	1.3
07CW09-43	206	16	18	1,990	1,990	61	2.35	sand	well	fine	grey-brown	2.2
07CW09-45	206	20	21.5					sand	well	fine	tan	5.5
07CW09-46	206	24	28					sand	well	fine	light tan	30
07CW09-55	211	4	6	1,863	1,863	60	2.24	sand	mod.	fine to coarse	lt. brown to brown	1.7
07CW09-49	211	12	13	865	865	31	2.01	sand	well	fine	lt. brown	65.6

APPENDIX A: LOGGED SOIL DATA

Sample ID	Location	Sample Interval Top	Sample Interval Bottom	Total Mass (g)	Soil Mass (g)	length (cm)	Density (g/mL)	Media	Sorting	Grain Size	Color	OVA
07CW09-52	211	20	21	987	987	31	2.30	sand	well	fine	grey	21.9
07CW09-53	211	21	22.2	1,072	1,072	34.5	2.24	sand	well	fine	grey	167
07CW09-54	211	24	28					clay	well	clay	grey	22
07CW09-56	213	0	1	769	769	31	1.79	sand	poor	silt to coarse sand	reddish-brown to black	1.5
07CW09-57	213	1	2.7	1,534	1,534	51	2.17	sand	well	fine	lt. brown	1.8
07CW09-65	213	4	6	1,748	1,748	61	2.07	sand	well	fine	lt. to dark brown	1.8
07CW09-66	213	6	7.8	1,732	1,732	55	2.27	sand	mod.	fine to coarse sand	lt. brown	1.4
07CW09-67	213	8	9	982	982	31	2.29	sand	well	fine	lt. brown	1.5
07CW09-68	213	9	10.5	1,288	1,288	46.5	2.00	sand	mod.	fine to coarse sand	lt. brown	2.4
07CW09-58	213	12	13	1,039	1,039	31	2.42	sand	well	fine	lt. brown	4.3
07CW09-59	213	13	14.3	1,223	1,223	40.5	2.18	sand	well	fine	lt. brown	2.5
07CW09-60	213	16	17	1,018	1,018	31	2.37	sand	well	fine	lt. brown	2.5
07CW09-61	213	17	18.7	1,552	1,552	52.5	2.13	sand	well	fine	lt. tan to grey	1.8
07CW09-62	213	20	21	832	832	31	1.94	sand	well	fine	grey	1.5
07CW09-63	213	21	22.5	1,324	1,324	49	1.95	sand	well	fine	grey	23.9
07CW09-64	213	24	28					sand	well	fine	grey	13.9
07CW09-69	215	0	2	1,683	1,683	61	1.99	sand	poor	silt, sand, and gravel	lt. brown/ brn. black@surface	1.3
07CW09-77	215	4	5	874	874	31	2.03	sand	mod.	fine to coarse	dark brown	1.5
07CW09-78	215	5	6.8	1,745	1,745	57	2.21	sand	well	fine	grey to dark grey	1.4
07CW09-79	215	8	9	987	987	31	2.30	sand	well	fine	lt. tan to brown	3.3
07CW09-80	215	9	10.5	1,414	1,414	47	2.17	sand	well	fine	brown	4.3
07CW09-70	215	12	13	1,009	1,009	31	2.35	sand	well	fine	grey to black	3.2
07CW09-71	215	13	14.4	1,247	1,247	43	2.09	sand	well	fine	grey to dark grey	2.9
07CW09-72	215	16	17	1,002	1,002	31	2.33	sand	well	fine	brownish grey	1.6

APPENDIX A: LOGGED SOIL DATA

Sample ID	Location	Sample Interval		Total Mass	Soil Mass	length	Density	Media	Sorting	Grain Size	Color	OVA
		Top	Bottom	(g)	(g)	(cm)	(g/mL)					
07CW09-75	215	21	22.7	1,646	1,646	52	2.29	sand	well	fine	grey	72.1
07CW09-76	215	24	28					sand	well	fine	grey w/ iron stains	999

Totals:	**102,358**	**g**	**2.17**	**g/cm^3**
	102	**kg**	**135**	**lb/ft^3**
	225	**lb**		

APPENDIX B: ZVI-CLAY GROUT MIXTURE DETAILS

Column ID	Category	Water (mL)	Bentonite (g)	Iron Amount (g)	Iron Source	$NaHCO_3$ (g)	Cement (g)
W-1	Unmixed control	--	--	--	--	--	--
W-2	Mixed control	1327	100	--	--	--	--
W-3	ZVI-Clay (1%)	1327	100	100	Peerless	--	--
W-4	ZVI-Clay (1%)	1327	100	100	GMA	--	--
W-5	ZVI-Clay (1%)	1327	100	100	QMP	--	--
W-6	ZVI-Clay (3%)	1327	100	300	Peerless	--	--
W-7	ZVI-Clay (3%)	1327	100	300	GMA	--	--
W-8	ZVI-Clay (3%)	1327	100	300	QMP	--	--
W-9	ZVI-Clay ($NaHCO_3$)	1327	100	100	Peerless	50	--
W-10	ZVI-Clay ($NaHCO_3$)	1327	100	100	GMA	50	--
W-11	ZVI-Clay ($NaHCO_3$)	1327	100	100	QMP	50	--
W-12	ZVI-Clay (cement)	1327	100	100	Peerless	--	100
W-13	ZVI-Clay (cement)	1327	100	100	GMA	--	100
W-14	ZVI-Clay (cement)	1327	100	100	QMP	--	100

APPENDIX C: BATCH REACTOR STUDY RESULTS TABLE

Column number	Sample Time ID	Treatment	Reaction Time (days)	TCE (mg/kg)	PCE (mg/kg)
1	0	Unmixed control	0.00	233.1	0.097
1	A	Unmixed control	3.21	262.2	0.134
1	B	Unmixed control	7.17	345.1	0.176
1	C	Unmixed control	28.21	367.6	0.186
1	D	Unmixed control	59.13	240.7	0.116
2	0	Mixed control	0.00	312.1	0.089
2	A	Mixed control	3.19	351.8	0.198
2	B	Mixed control	7.15	282.5	0.119
2	C	Mixed control	28.19	332.8	0.177
2	D	Mixed control	59.10	278.6	0.142
3	0	1% Peerless	0.00	278.4	0.107
3	A	1% Peerless	3.16	403.2	0.209
3	B	1% Peerless	7.12	281.9	0.113
3	C	1% Peerless	28.16	259.5	0.153
3	D	1% Peerless	59.08	189.7	0.134
4	0	1% GMA	0.00	345.2	0.101
4	A	1% GMA	3.02	342.3	0.185
4	B	1% GMA	6.98	304.4	0.130
4	C	1% GMA	28.02	179.7	0.118
4	D	1% GMA	58.94	48.3	0.060
4	D(dup)	1% GMA	58.94	55.1	0.089
5	0	1% QMP	0.00	295.0	0.119
5	A	1% QMP	3.00	301.9	0.161
5	B	1% QMP	6.96	275.8	0.130
5	C	1% QMP	28.00	332.6	0.181
5	D	1% QMP	58.92	216.0	0.107
5	D(dup)	1% QMP	58.92	262.7	0.184
6	0	3% Peerless	0.00	167.9	0.055
6	A	3% Peerless	2.97	257.9	0.145
6	B	3% Peerless	6.93	164.7	0.092
6	C	3% Peerless	27.97	80.2	0.095
6	D	3% Peerless	58.89	11.9	0.071
6	D(dup)	3% Peerless	58.89	9.2	ND

APPENDIX C: BATCH REACTOR STUDY RESULTS TABLE

Column number	Sample Time ID	Treatment	Reaction Time (days)	TCE (mg/kg)	PCE (mg/kg)
7	0	3% GMA	0.00	254.3	0.075
7	A	3% GMA	2.95	302.3	0.179
7	B	3% GMA	6.91	164.4	0.093
7	C	3% GMA	27.95	2.4	0.044
7	D	3% GMA	58.87	0.1	ND
7	D(dup)	3% GMA	58.87	ND	ND
8	0	3% QMP	0.00	278.8	0.089
8	A	3% QMP	2.92	344.3	0.176
8	B	3% QMP	6.88	239.5	0.099
8	C	3% QMP	27.92	219.6	0.120
8	D	3% QMP	58.84	88.7	0.059
9	0	1% P (NaHCO3)	0.00	191.8	0.058
9	A	1% P (NaHCO3)	3.10	296.3	0.162
9	B	1% P (NaHCO3)	7.03	292.2	0.177
9	C	1% P (NaHCO3)	28.10	250.5	0.177
9	D	1% P (NaHCO3)	59.01	194.1	0.146
9	D(dup)	1% P (NaHCO3)	59.01	194.7	
10	0	1% GMA (NaHCO3)	0.00	215.1	0.069
10	A	1% GMA (NaHCO3)	3.07	361.6	0.216
10	B	1% GMA (NaHCO3)	7.01	294.3	0.178
10	C	1% GMA (NaHCO3)	28.07	144.5	0.080
10	D	1% GMA (NaHCO3)	58.99	40.8	0.037
10	D(dup)	1% GMA (NaHCO3)	58.99	45.1	
11	0	1% QMP (NaHCO3)	0.00	147.9	0.074
11	A	1% QMP (NaHCO3)	3.05	374.6	0.205
11	B	1% QMP (NaHCO3)	6.99	338.3	0.187
11	C	1% QMP (NaHCO3)	28.05	252.3	0.159
11	D	1% QMP (NaHCO3)	58.97	160.5	0.100

APPENDIX C: BATCH REACTOR STUDY RESULTS TABLE

Column number	Sample Time ID	Treatment	Reaction Time (days)	TCE (mg/kg)	PCE (mg/kg)
12	0	1% P (cement)	0.00	186.7	0.122
12	A	1% P (cement)	2.91	651.0	0.371
12	B	1% P (cement)	7.06	449.2	0.227
12	C	1% P (cement)	27.97	341.4	0.169
12	D	1% P (cement)	58.93	303.0	0.157
13	0	1% GMA (cement)	0.00	244.5	0.083
13	A	1% GMA (cement)	2.89	341.3	0.190
13	B	1% GMA (cement)	7.03	283.4	0.151
13	C	1% GMA (cement)	27.95	265.1	0.140
13	D	1% GMA (cement)	58.91	222.2	0.123
13	D(dup)	1% GMA (cement)	58.91	231.9	
14	0	1% QMP (cement)	0.00	153.1	0.063
14	A	1% QMP (cement)	2.87	371.5	0.187
14	B	1% QMP (cement)	7.01	379.4	0.186
14	C	1% QMP (cement)	27.93	318.8	0.151
14	D	1% QMP (cement)	58.89	270.9	0.135

APPENDIX D: QA/QC

Column number	Sample Time ID	Treatment	Reaction Time (days)	TCE (mg/kg)	PCE (mg/kg)
4	D	1% GMA	58.94	48.3	0.060
4	D(dup)	1% GMA	58.94	55.1	0.089
5	D	1% QMP	58.92	216.0	0.107
5	D(dup)	1% QMP	58.92	262.7	0.184
6	D	3% Peerless	58.89	11.9	0.071
6	D(dup)	3% Peerless	58.89	9.2	ND
7	D	3% GMA	58.87	0.1	ND
7	D(dup)	3% GMA	58.87	ND	ND
9	D	1% P (NaHCO3)	59.01	194.1	0.146
9	D(dup)	1% P (NaHCO3)	59.01	194.7	
10	D	1% GMA (NaHCO3)	58.99	40.8	0.037
10	D(dup)	1% GMA (NaHCO3)	58.99	45.1	
13	D	1% GMA (cement)	58.91	222.2	0.123
13	D(dup)	1% GMA (cement)	58.91	231.9	

ADDENDUM TO FINAL REPORT

Bench-Scale Evaluation of ZVI-Clay
OMC Plant 2
Waukegan, Illinois

Developed by

Colorado State University
Center for Contaminant Hydrology

Colorado State University
Civil and Environmental Engineering
CCH
Center for Contaminant Hydrology

For
CH2M HILL, Inc.

July 23, 2007

Introduction

This addendum to the Final Report (dated June 5, 2007) presents results of additional samples that were collected from the reactors on June 27, 2007. The Final Report presented data collected after approximately 2 months of reaction time. Updated data presented herein reflects treatment results after approximately 6 months of reaction time. The primary objective of this final sample round was to evaluate the sustainability of degradation rates noted after 2 months. This report presents updated sample data and kinetics evaluation.

TCE Data

TCE degradation data is discussed in this section. A table showing TCE concentrations versus time in each column is included in Appendix A.

Control Columns

TCE concentrations in the control columns are presented in Figure 1. No iron was added to these columns. TCE levels are relatively constant over 170 days. Stable concentrations in the control columns provide evidence that concentration reductions in treated columns did result from addition of iron.

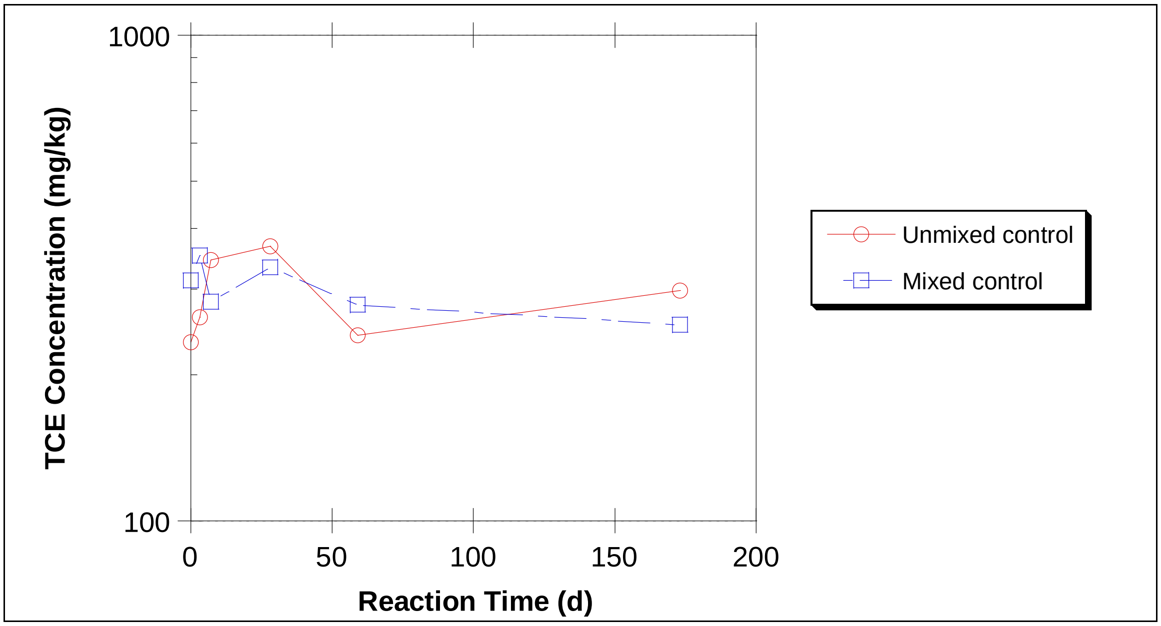

Figure 1. TCE concentration vs. time in the control columns.

Evaluation of Iron Source and Amount

TCE concentrations in columns containing 1% and 3% iron are presented in Figure 2 and Figure 3, respectively. Iron was evaluated from three sources: Peerless, GMA, and QMP.

In general, degradation appears to follow a pseudo-first order kinetic model through 6 months (made apparent by linear appearance on a semi-logarithmic scale). Data from the column containing 3-percent GMA iron appears to stray from the pseudo-first order model at a TCE concentration of less than 0.1 mg/kg. At low concentrations, the reaction rate is possibly slowed due to limited number of contaminant particles remaining that are available for reaction.

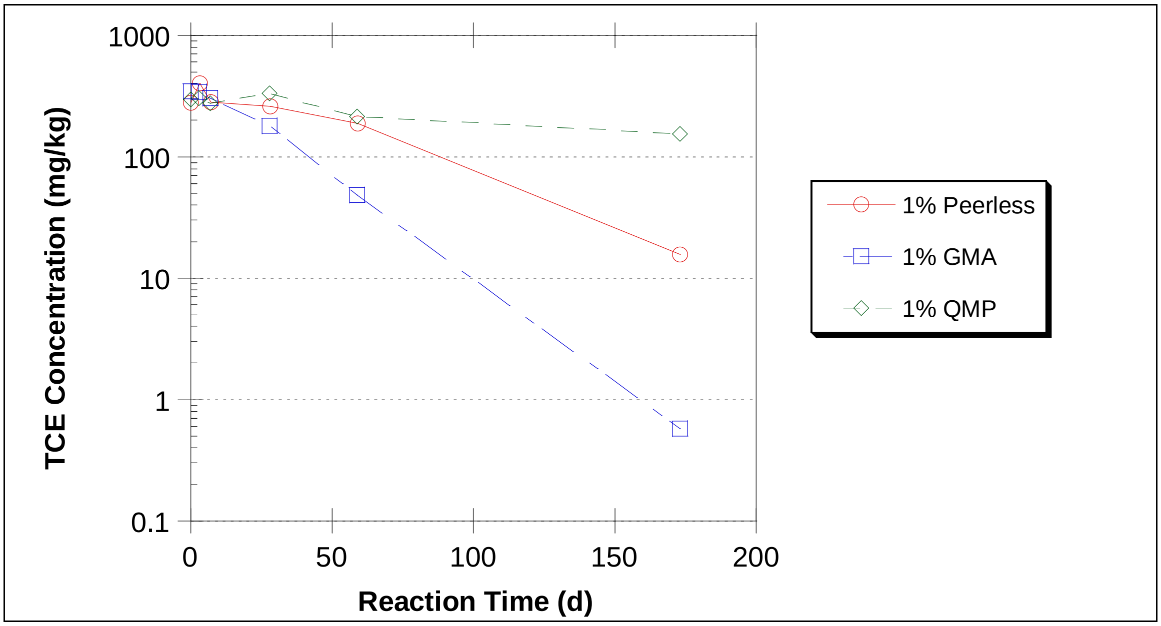

Figure 2. TCE concentration vs. time in 1-percent iron columns.

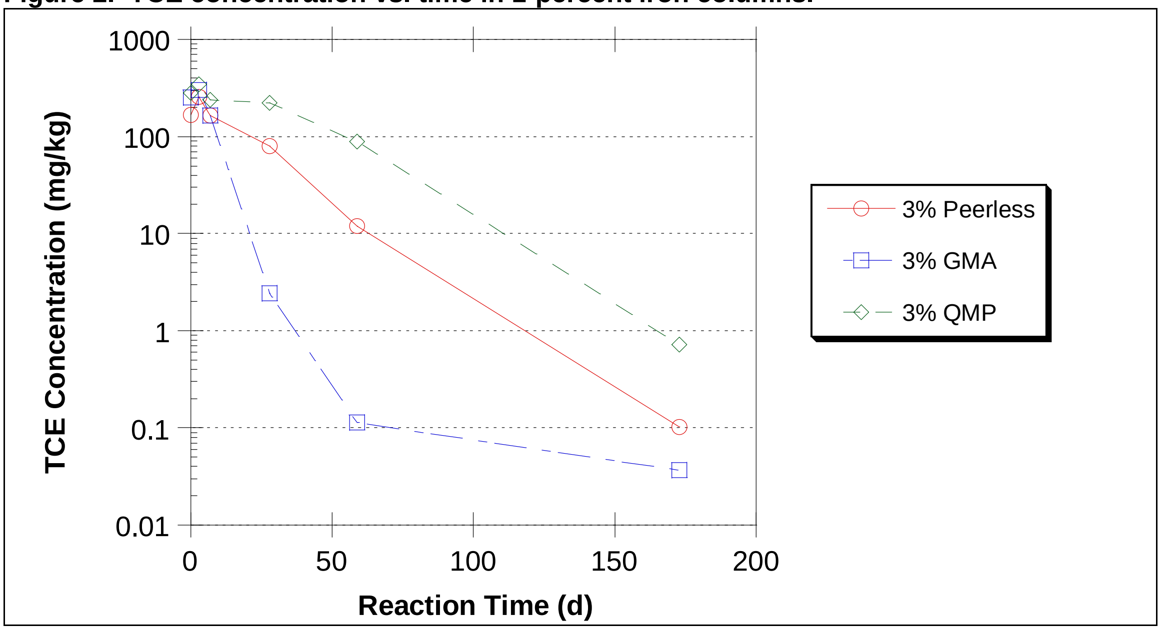

Figure 3. TCE concentration vs. time in 3-percent iron columns.

Addition of Sodium Bicarbonate

TCE concentrations in columns containing 1-percent iron and 0.5% sodium bicarbonate ($NaHCO_3$) are presented in Figure 4. In general, addition of sodium bicarbonate did not significantly affect treatment performance.

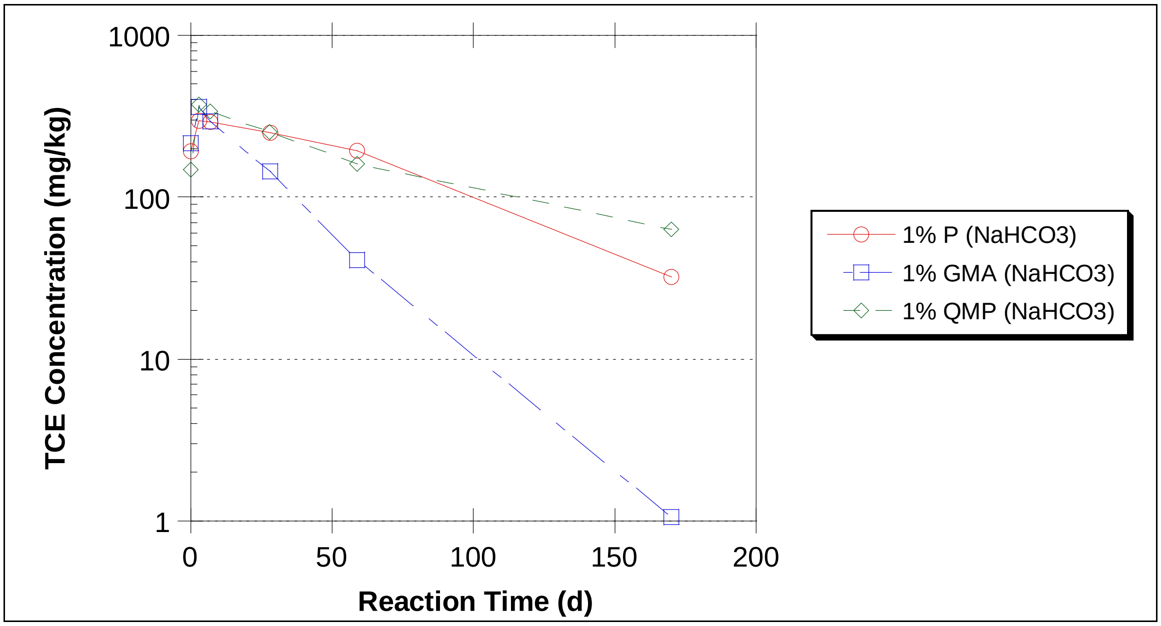

Figure 4. TCE concentration vs. time in columns containing 1-percent iron and 0.5-percent sodium bicarbonate ($NaHCO_3$).

Addition of Cement

TCE concentrations in columns containing 1-percent iron and 1-percent cement are presented in Figure 5. Cement used for the study was an off-specification product from a source local to the site and was provided by CH2M Hill. Cement addition noticeably hindered treatment performance. This is likely due to the high pH conditions.

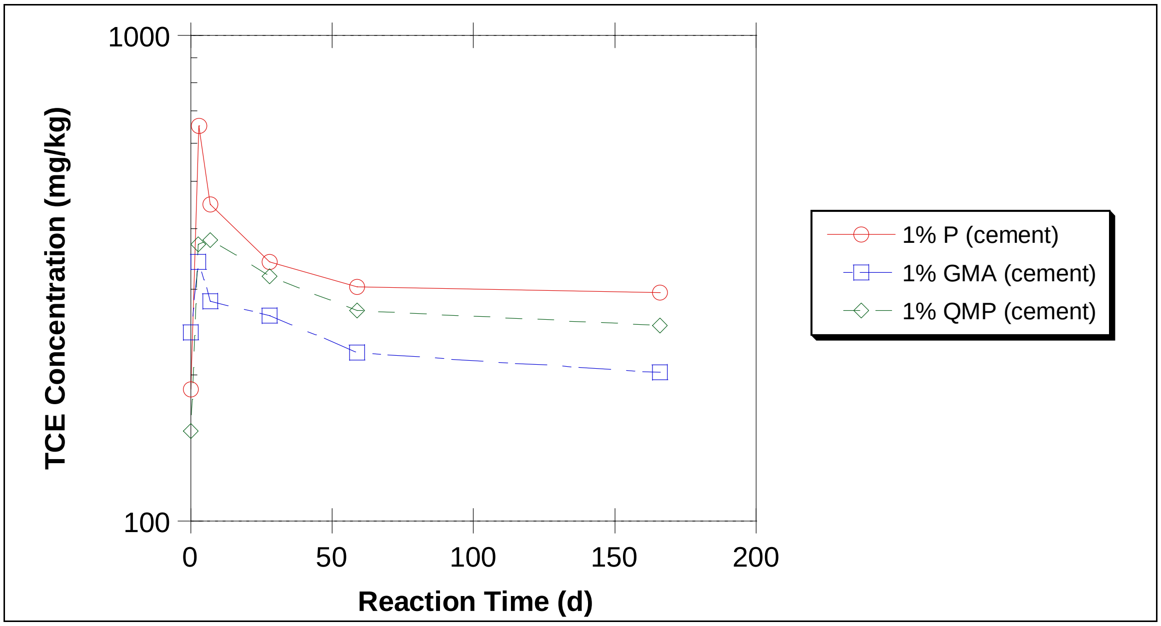

Figure 5. TCE concentration vs. time in columns containing 1-percent iron and 1-percent cement (off-specification product from source local to the site).

Reaction Kinetics

A useful method for comparison of different treatments is the half-life. Contaminant half-lives were estimated using pseudo-first order assumptions. Calculated half-lives based on 2-month data and 6-month data are shown in Table 1.

In most cases, measured half-lives did not change significantly based on 6-month data. This indicates that degradation rates were generally sustained between two months and six months. Notable exceptions include the following treatments: 3-percent GMA iron, no-iron controls, and cement addition. Treatment using 3-percent GMA iron achieved the lowest TCE concentrations in the study (0.04 mg/kg). Below 0.1 mg/kg the concentration strays from the initial pseudo-first order pattern. This is likely due to depletion of TCE that is available for reaction. Remaining TCE may be irreversibly adsorbed in the soil matrix. Other columns that showed significant change in half-lives include the no-iron controls and cement-added treatments. All of these columns had large half-lives to begin with, but showed much-increased half-lives after the 6 month data. In the control columns, this indicates that concentrations are relatively stable with no iron added. In the case of cement-added columns, initially slow degradation rates were further inhibited with the additional time.

Table 1. Estimated TCE Half-Lives.

Column ID	Description	TCE Half-life: 2 month data* (days)	TCE Half-life: 6 month data (days)
W-1	Unmixed control	210	3,466
W-2	Mixed control	301	495
W-3	1% Peerless	63	40
W-4	1% GMA	20	19
W-5	1% QMP	141	178
W-6	3% Peerless	13	15
W-7	3% GMA	5	**
W-8	3% QMP	32	20
W-9	1% P ($NaHCO_3$)	90	57
W-10	1% GMA ($NaHCO_3$)	18	21
W-11	1% QMP ($NaHCO_3$)	47	81
W-12	1% P (cement)	95	462
W-13	1% GMA (cement)	108	315
W-14	1% QMP (cement)	116	1,155

Notes:
* 2-month half-lives were presented in the Final Report (June 5, 2007)
** Degradation rate ceased to follow first-order kinetics after 2 month data was collected. As such, an updated half-life is not calculated.

Conclusions

Updated results from the 6-month study do not significantly alter the conclusions presented in the final report. Key observations include the following:

- Concentrations in control columns remained stable through 6 months. This indicates that reductions in TCE levels in treated columns was indeed due to addition of iron.
- Pseudo-first order kinetics generally held through six months of reaction time.
- Treatment via 3-percent GMA iron reduced TCE to 0.04 mg/kg. Below 0.1 mg/kg, treatment no longer follows first-order kinetics. This is likely due to reduction in the amount of TCE that is available for reaction. Remaining TCE may be irreversibly adsorbed in the soil matrix.

Appendix A: Sample Results

Column number	Treatment	Reaction Time (d)	TCE (mg/kg)
1	Unmixed control	0	233.1
1	Unmixed control	3	262.2
1	Unmixed control	7	345.1
1	Unmixed control	28	367.6
1	Unmixed control	59	240.7
1	Unmixed control	173	298.1
2	Mixed control	0	312.1
2	Mixed control	3	351.8
2	Mixed control	7	282.5
2	Mixed control	28	332.8
2	Mixed control	59	278.6
2	Mixed control	173	253.7
3	1% Peerless	0	278.4
3	1% Peerless	3	403.2
3	1% Peerless	7	281.9
3	1% Peerless	28	259.5
3	1% Peerless	59	189.7
3	1% Peerless	173	15.8
4	1% GMA	0	345.2
4	1% GMA	3	342.3
4	1% GMA	7	304.4
4	1% GMA	28	179.7
4	1% GMA	59	48.3
4	1% GMA	59	55.1
4	1% GMA	173	0.58
5	1% QMP	0	295.0
5	1% QMP	3	301.9
5	1% QMP	7	275.8
5	1% QMP	28	332.6
5	1% QMP	59	216.0
5	1% QMP	59	262.7
5	1% QMP	173	154.3
6	3% Peerless	0	167.9
6	3% Peerless	3	257.9
6	3% Peerless	7	164.7
6	3% Peerless	28	80.2
6	3% Peerless	59	11.9
6	3% Peerless	59	9.2
6	3% Peerless	173	0.10
7	3% GMA	0	254.3
7	3% GMA	3	302.3
7	3% GMA	7	164.4
7	3% GMA	28	2.4
7	3% GMA	59	0.11
7	3% GMA	59	
7	3% GMA	173	0.04

Column number	Treatment	Reaction Time (d)	TCE (mg/kg)
8	3% QMP	0	278.8
8	3% QMP	3	344.3
8	3% QMP	7	239.5
8	3% QMP	28	219.6
8	3% QMP	59	88.7
8	3% QMP	173	0.7
9	1% P (NaHCO3)	0	191.8
9	1% P (NaHCO3)	3	296.3
9	1% P (NaHCO3)	7	292.2
9	1% P (NaHCO3)	28	250.5
9	1% P (NaHCO3)	59	194.1
9	1% P (NaHCO3)	59	194.7
9	1% P (NaHCO3)	170	32.2
10	1% GMA (NaHCO3)	0	215.1
10	1% GMA (NaHCO3)	3	361.6
10	1% GMA (NaHCO3)	7	294.3
10	1% GMA (NaHCO3)	28	144.5
10	1% GMA (NaHCO3)	59	40.8
10	1% GMA (NaHCO3)	59	45.1
10	1% GMA (NaHCO3)	170	1.1
11	1% QMP (NaHCO3)	0	147.9
11	1% QMP (NaHCO3)	3	374.6
11	1% QMP (NaHCO3)	7	338.3
11	1% QMP (NaHCO3)	28	252.3
11	1% QMP (NaHCO3)	59	160.52
11	1% QMP (NaHCO3)	170	63.1
12	1% P (cement)	0	186.7
12	1% P (cement)	3	651.0
12	1% P (cement)	7	449.2
12	1% P (cement)	28	341.4
12	1% P (cement)	59	303.0
12	1% P (cement)	166	295.3
13	1% GMA (cement)	0	244.5
13	1% GMA (cement)	3	341.3
13	1% GMA (cement)	7	283.4
13	1% GMA (cement)	28	265.1
13	1% GMA (cement)	59	222.2
13	1% GMA (cement)	59	231.9
13	1% GMA (cement)	166	202.54
14	1% QMP (cement)	0	153.1
14	1% QMP (cement)	3	371.5
14	1% QMP (cement)	7	379.4
14	1% QMP (cement)	28	318.8
14	1% QMP (cement)	59	270.92
14	1% QMP (cement)	166	252.6